Bulletin
of
The Geological Society of America

VOLUME 65 December 1954 NUMBER 12, PART 1

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Subscription $15.00 per year.

Printing Office: Mt. Royal & Guilford Aves., Baltimore 2, Md.

Communications for publications should be addressed to The Geological Society of America, Dr. H. R. Aldrich, Secretary, 419 West 117 Street, New York, N. Y.

Please give notice of change of address 4 weeks in advance. Claims for non-receipt of the Bulletin of a given month must be sent to the Secretary of the Society before the end of the second succeeding month.

Entered as second-class matter at the Post Office at Baltimore, Md., under the Act of Congress of July 16, 1894.
Accepted for mailing at special rate of postage provided for in Section 1103 Act of October 3, 1917, authorized on July 8, 1918.

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BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 65, PP. 1151–1166 DECEMBER 1954

TRACE ELEMENTS IN PELITIC ROCKS

PART I: VARIATION DURING METAMORPHISM

BY DENIS M. SHAW

ABSTRACT

Sixty-three rocks of the pelitic Devonian Littleton formation of New Hampshire have been analyzed spectrographically for trace elements. The samples represent all grades of metamorphism from shales to sillimanite schists and gneisses. The average concentrations and standard deviations in ppm are: Ga, 19, 6.3; Cr, 110, 33; V, 120, 39; Li, 110, 104; Ni, 64, 26; Co, 18, 6.6; Cu, 18, 18; Sc, 14, 7.4; Zr, 200, 73; Y, 45, 20; Sr, 710, 310; Pb, 24, 12. Be, Mo, Sn, La, and Ag were usually below the sensitivity limits of 30, 10, 20, 100, and 1 ppm respectively. Ba almost always exceeds 1000 ppm.

Figures for individual analyses were grouped according to low- medium- or high-grade metamorphism. Statistical tests show a rather wide range in original composition, which suggests that it is unwise to deduce composition changes from a few analyses. The analyses, however, show that the concentration of most elements remained constant during regional metamorphism. Ni and Cu show a slight decrease, and Li and Pb a well-defined increase of the order of 100 per cent accompanying the metamorphism. This increase is a metasomatism at the trace-element level, which probably accompanies the potash-metasomatism encountered by Billings in the same formation.

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INTRODUCTION

Statement of Problem

Research in modern geochemistry has in the main been concerned with three main groups of materials—meteorites, igneous rocks, and sediments. The metamorphic rocks have scarcely been touched, although they are quantitatively the most important constituents of the earth's crust. Possibly this has resulted

from the opinion that ordinary metamorphic processes take place with no appreciable change in composition. Some analyses for major elements are available, although negligible compared with the thousands of analyzed eruptive rocks. In the case of the minor elements, there are only a few analyses, mostly semi-quantitative.

Nevertheless a vast literature on metasomatism, both factual and speculative (*e.g.* Lapadu-Hargues, 1949), deals with changes in the composition of metamorphic rocks. Moreover, it has been suggested from time to time that many metallic ore deposits may ultimately be derived from sedimentary rather than magmatic rocks. These processes involve changes in composition, but to find evidence of a change the original composition must be known, and, more important, the range in composition of the original must be defined. Unless the range is known, there are dangers of finding spurious trends. A statistical approach is therefore necessary, with application of the established discrimination tests.

Since statistical tests are most reliable when many analyses are available and since few petrologists can afford large numbers of wet analyses, the spectrograph is most useful, for analyses are rapid and cheap, and reasonable precision is possible for minor elements. (As yet the spectrograph is not sufficiently precise for most major elements.) The writer investigated the composition of metamorphic rocks of pelitic composition, restricting the inquiry at first to a group of minor elements suitable for spectrographic determination. Soon after the work was started it seemed advisable to investigate major elements as well, and these methods and results will be reported in Part III. (Shaw, in preparation).

The first requirement was a field area that contains a pelitic formation in a wide variety of metamorphic conditions, including unaltered shales (for all samples must represent the same stratigraphic unit). Few areas satisfy this requirement, but the Appalachian region of New Hampshire seems ideal. The complex geology of this area has been unravelled by Billings and his associates, and the Devonian Littleton formation has been traced from fossiliferous shales near the Connecticut River to sillimanite gneisses in the White Mountains and beyond. Samples were collected in the summers of 1951 and 1952.

Acknowledgments

The writer is indebted to Professor M. P. Billings, Harvard University, for suggestions and discussion of the problem and to Professor J. D. Bankier Dept. of Mathematics, McMaster University, for advice on statistical methods. Generous financial support was given by the Penrose Bequest of The Geological Society of America, the National Research Council of Canada, and the Geological Survey of Canada.

Sample Material

In planning the work it was decided to sample as wide an area as possible. About half the samples came from the White Mountains and half from the western and southwestern regions of New Hampshire. Unfortunately, the low-grade rocks are confined to a relatively small area in northwestern New Hampshire so these samples are of necessity closely spaced. Sample localities are listed in Table 1.

At each locality 2 pounds or more of small fragments of representative fresh rock were collected, to get a sample representative of the outcrops, and hand specimens of each rock type sampled were collected. In the laboratory all the small fragments were broken to about pea size, mixed and crushed in a steel mortar, then quartered. Opposite quarters were taken and ground in an agate mortar by the Fisher Automatic Grinder to pass 150-mesh silk. The abundance of mica makes this comminution slow, and a nearly pure mica sample was always the last to be ground. The resulting powder was thoroughly mixed. With some of the banded gneisses samples of the light and dark portions of the rock were crushed independently. In a few cases the sample was of necessity made from a single hand specimen, but this was avoided wherever possible.

While collecting the rocks, the general aim of sampling a pelitic formation was kept in mind. No formation is uniform, either in vertical or horizontal direction and it is difficult to decide what is representative and what is not. Obvious quartzites and limestones were

TABLE 1.—SAMPLE LOCALITIES

Number	Rock description	Locality	Quadrangle	Reference
L 1	Black-gray shale	0.8 mi. N. Cemetery, Littleton	Littleton	Billings (1937a)
L 2	Black slate with pyrite	Slate Ledge quarry		
L 3	Black slate	5/8 mi. W. Walker Mt.		
L 4	Gray argillite	1/4 mi. W. Fitch Farm		
L 5	Garnetiferous black slate	Gale River, just above volcanic member		
L 6	Chloritoid phyllite	Gale River, 100 yds. east of L 5		
L 7	Black quartzite with occasional garnets	Gale River, 150 yds. east of L 5		
L 8	Black slate	Mormon Hill		
L 9	Gray shale	1/4 m. E. Ogontz Lake		
L 10	Slate	1/4 m. E. Clough Hill School		
L 11	Slate	1 m. N.E. Moulton Hill		
L 12	Staurolite garnet schist	E. side Pearl Lake	Moosilauke	Billings (1937a)
L 13	Garnet staurolite schist	1 m. along road N.N.W. from Sugar Hill		
L 14	Black slate	2 m. N. Littleton	Littleton	Billings (1937a)
L 18	Garnet schist	1/2 m. N.E. Profile Golf Club	Franconia	Williams and Billings (1938)
L 20	Mica gneiss	1/2 m. N.E. Profile Golf Club		
L 25	Banded gneiss: dark layer	1/2 mi. S. North Woodstock		
L 26	Banded gneiss: felsic layer	1/2 mi. S. North Woodstock		
L 27	Banded gneiss	2 1/2 mi. S. North Woodstock		
L 28	Micaceous sandy slate	1 1/2 mi. N.W. East Haverhill station		
L 29	Sillimanite garnet gneiss	1 mi. S.E. West Rumney P.O.	Rumney	Fowler-Billings and Page (1942)
L 31	Garnet schist	Summit Mt. Moosilauke	Moosilauke	Billings (1937a)
L 32	Garnet schist	4250 ft. elevation on trail below Mt. Blue		
L 33	Feldspathic gneiss	4 mi. W. Tamworth	Chocorua	Smith et al. (1939)
L 36a	Banded gneiss: dark layer	1 mi. N.W. Spruce Mt.	N. Conway	Billings (1928)
L 36b	Banded gneiss: felsic	1 mi. N.W. Spruce Mt.		
L 38	Pseudo-andalusite schist	Crystal Cascades on Cutler river	Mt. Washington	Billings et al. (1946)
L 39	Banded sillimanite gneiss	Jefferson Notch road, 1/4 mi. N. of BM 2049		
L 40	Sillimanite schist	1/8 mi. S. jct. Dolly Copp road and Pinkham Notch highway		
L 41	Sillimanite gneiss	1/2 mi. S. Glen House		
L 42	Pseudo-andalusite schist	4100 ft. on Tuckerman Ravine trail		
L 43	Banded gneiss	Summit Mt. Monroe		

TABLE 1—*Continued*

Number	Rock description	Locality	Quadrangle	Reference
L 44	Pseudo-andalusite schist	Summit Mt. Washington		
L 45	Pseudo-andalusite schist	3000 ft. on Tuckerman Ravine trail		
L 46	Andalusite schist	2800 ft. on Tuckerman Ravine trail		
L 48	Staurolite schist	2750 ft. on Daniel Webster trail		
L 49	Pseudo-andalusite schist	5200 ft. on Osgood trail, Mt. Madison		
L 50	Garnet schist	Jct. of Osgood and Daniel Webster trails		
L 53	Mica gneiss	Summit Mt. Monadnock	Monadnock	Fowler-Billings (1949)
L 54	Sillimanite-rich schist	Thoreau Seat, ¼ mi. E. Halfway House, Mt. Monadnock		
L 55	Sillimanite-rich schist	¼ mi. N.E. of the east end of Dublin Lake		
L 56	Mica gneiss	S.E. end Silver Lake		
L 57	Sillimanite schist	Beechwood Corner, 3 mi. W. Fitzwilliam depot		
L 58	Sillimanite-hornfels (inclusion in monzonite)	5 mi. N. Winchester	Keene-Brattleboro	Moore (1949)
L 61	Garnet schist	1 mi. S. Hinsdale		
L 62	Muscovite schist	1 mi. S. Hinsdale		
L 63	Phyllonite	E. bank Connecticut River, 2 mi. S. Brattleboro		
L 64	Staurolite-garnet schist	Chesterfield		
L 65	Psammitic garnet schist	2 mi. W. Chesterfield on highway		
L 66	Staurolite schist	Spofford		
L 67	Garnet phyllite	1¼ mi. N. Westmoreland depot	Bellows' Falls	Kruger (1946)
L 68	Sericite schist	2 mi. S. North Walpole		
L 69	Staurolite-garnet schist	2 mi. N.E. Alstead on Cold river		
L 70	Sericite schist	Acworth		
L 71	Sericite slate	2 mi. N. Claremont		
L 73	Kyanite garnet schist (Orfordville formation)	1 mi. S.S.E. North Thetford	Mt. Cube-Mascoma	Hadley and Chapman (1939)
L 74	Feldspathic schist	1½ mi. N. Lyme Centre		
L 75	Psammitic garnet schist	2 mi. N. Mascoma		
L 76	Garnet schist	1 mi. E. Mascoma		
L 77	Garnet schist	6 mi. N.N.W. North Grantham, Route 10		
L 78	Sillimanite gneiss	N.E. side Tewkesbury Pond	Cardigan	Fowler-Billings and Page (1942)
L 79	Mica gneiss	1 mi. S.W. South Alexandria		

TABLE 1—*Continued*

Number	Rock description	Locality	Quadrangle	Reference
L 80	Garnet sillimanite gneiss	2.7 mi. S. Plymouth on U.S. 3		
L 81	Garnet sillimanite gneiss	1 mi. S. West Campton	Plymouth	Moke (1946)
L 82	Staurolite garnet schist	Summit of Garnet Hill	Moosilauke	Billings (1937a)
L 84	Mica schist	Black Brook along Beech Hill trail		
L 86	Garnet staurolite phyllite	½ mi. N.N.E. of L 85		
L 87	Fluvio-glacial clay	Kirk's Ferry, Gatineau R., Ottawa		
L 88	Black slate	Burnt Creek, New Quebec, Labrador		
L 89	Slate	Melbourne, Quebec		
S 66	Corycium phyllite	Tähtinen, Aitolahti, Finland		

ignored, but there is continual variation between pelitic and psammitic facies. In low-grade rocks, the shaly or slaty texture is a sufficient criterion for distinction; in the schists the abundance of micas and quartz and the presence of sillimanite, andalusite, kyanite, staurolite, and red garnet are good indicators of original pelitic composition. The presence of much quartz indicates a psammitic composition. There are clear similarities in composition between most samples, making it easy to decide whether or not they should be included with the averages. In general, the results vindicate the sampling procedure.

For a detailed account of the mineralogy of the rocks, the reader is referred to the work of Billings (1941) and Kruger (1946).

ANALYTICAL METHODS

General

Quantitative spectrochemical methods were used, employing the D.C. arc. Since about 19 elements were to be determined and the number of samples was large, the elements were divided into two groups and determined by two appropriate methods.

In work of this kind, in which the results are to be handled statistically, adequate precision figures must be obtained. Accordingly, the setting up of working curves has been treated as a problem in linear regression, and the curves have been drawn by the least-squares method which also yields a measurement of precision.

Determination of Involatile Elements

The methods of determination of Be, Cr, V, Mo, Ni, Co, Sc, Zr, Y, Sr, and Ba are presented in Table 2. The method of processing was developed to prevent the formation of troublesome blisters on plates III-F (Table 2).

Line-blackening was measured by an ARL Photodensitometer, choosing wherever possible a step giving a galvanometer reading between 10 and 60 (clear plate value 100; maximum blackness 0). Background was measured for each line, on a denser step. A gamma curve was drawn for each plate, using seven or eight steps of the lines Fe 3418.512 (plate S.A.I.) and Fe 4427.312 (plate III-F). The galvanometer reading for each line was converted to an arbitrary intensity figure (corrected for background) relative to the seventh step, on a calculating board of the type described by Honerjäger-Sohm and Kaiser (1944). The figures so obtained are referred to as y values. Working curves were constructed, relating the y values to concentration of the individual elements, from artificial standards.

The standards were prepared from Johnson-Matthey "Specpure" oxides of the metals, mixed with a "claylike" matrix. Concentration steps of 1000, 316, 100, 31.6, 10, and 3 ppm

were prepared by dilution with the matrix, a mixture of silica (64%), alumina (24%), nepheline syenite (8%), and potassium chloride (4%). These materials were first carefully checked for absence of contamination by the analysis elements. Contamination by strontium and barium, was found in the silica used, and a fresh set of standards of similar composition was prepared with the addition of 2.5 per cent Fe_2O_3. The absence of iron from the first matrix is the chief difference between it and a clay, but comparison of a standard made from the matrix and another made from the matrix plus 10 per cent Fe_2O_3 showed no noticeable differences in line density. The standards were therefore quite satisfactory for analyzing clay and schist samples.

Spectral lines used are listed in Table 3 (taken from Harrison, 1939). For chromium, nickel, and vanadium, the concentration range could not be covered by one line, so two were used. I indicates the more sensitive and II the less sensitive line. On many samples a figure could be obtained from both lines.

The spectral lines were chosen to be as free as possible from interference with adjacent lines. In the case of Y 4374.935 Å, there is a coincidence with Mn 4374.947 Å, which is troublesome in basic igneous rocks (L. H. Ahrens, personal communication). The manganese content is probably not high enough to cause serious interference in the present samples, but the possibility must be borne in mind. There is also a near coincidence of Cr 3005.057 Å and Fe 3005.306 Å. Occasionally this iron line was too intense to permit accurate measurement of the chromium line.

Some samples were outside the concentration range for strontium and barium and were therefore analyzed after diluting with silica. A blank determination on the silica gave a correction factor, but these determinations are excluded from the calculations.

This analytical procedure is a total-energy

TABLE 2.—ANALYSIS METHOD FOR INVOLATILE ELEMENTS

Spectrograph	Jarrell-Ash 21-foot grating, Wadsworth mount, dispersion 5 Å/mm in first-order spectrum
Power source	ARL Rectifier unit
Excitation	250 volts D.C., 8½ amperes, 14 mm arc-gap, cathode excitation
Slit and Sector	20 microns; 7-step sector, step-ratio log $I_0/I = 0.2$
Optical System	Light from lower 9 mm of arc-column focused on slit by 100 cm focal-length cylindrical quartz lens with axis vertical
Exposure	165 seconds
Electrodes	Lower, ⅛ in. graphite rod ("Special" grade), bored to depth of 6 mm and diameter of 1.5 mm. Upper, ⅛ in. graphite rod ("Special" grade)
Plates	Eastman Kodak S.A.-1 2250–3550 Å III-F 3550–4850 Å
Processing	20 seconds in distilled water, 4 min (S.A.-1) and 3 min (III-F) in D-19 developer at 20°C, 10 seconds wash, 10 seconds stop-bath (5% acetic acid), 10 seconds wash, 15 min. in Acid Fixing bath, 15 min wash
Sample	10 mg sample of 1:1 mixture of rock powder and graphite powder, triplicate analysis
Calibration	Iron-arc with heavy conical electrodes, 3 amperes, 7 seconds anode excitation

TABLE 3.—SPECTRAL LINES FOR INVOLATILE ELEMENTS

Be	2348.610 Å	Mo	3193.973 Å	Cr I	4254.346 Å
Ni II	3003.629	Zr	3391.975	La	4333.734
Cr II	3005.057	Ni I	3414.765	Y	4374.935
V II	3060.460	Co	3453.505	Ba	4554.042
V I	3185.396	Sc	4246.829	Sr	4607.331

method. Such a method is prone to error, unless rigid control of sample size, arcing, and plate processing can be achieved. To avoid these difficulties, an internal standard is frequently used and in many cases gives higher precision. In the present study palladium was used as internal standard in preliminary work, as suggested by Ahrens (1951). However, the precision so obtained was lower than when the internal standard was ignored and a total-energy method followed. This, no doubt, was due to the necessity of employing cathode excitation to obtain high sensitivity.

Table 4.—Analysis Method for Volatile Elements

Excitation	250 volts D.C., 5 amperes, 9 mm arc-gap, anode excitation
Optical System	Light from whole arc-column focused on slit by 100 cm focal-length cylindrical quartz lens with vertical axis
Exposure	110 seconds
Plates	Eastman Kodak S.A.-1. 2700-4000 Å
Processing	3 min. in D-19 developer, 10 seconds stop-bath, 10 min. fix, 15 min. wash
Sample	Approximately 12 mg of 9:1 mixture of rock powder and flux; flux was NaCl containing 0.1% In (as oxide) for internal standard; triplicate analysis
Calibration	*see text*

Table 5.—Spectral Lines for Volatile Elements

Ga	2943.64 Å	Cu	3273.96 Å
Sn	3175.05	Ag	3382.89
Li	3232.67	Pb	3683.47

Determination of Volatile Elements

This group includes Ga, Sn, Li, Cu, Ag, and Pb, and details of the method which differ from the preceding group are presented in Table 4.

Densitometry was generally similar to the previous method. For calibration the line *In* 3258.564 was used, checking the gamma curve for each plate. The indium served also as internal standard, and the usual log-intensity ratio was calculated. Background corrections were applied. In addition, the line *In* 3256.090 was treated as an analysis line, and the intensity ratio calculated for every sample. These ratios were useful to check the coincidence of *In* 3258.564 and *Mn* 3258.413. In most samples this coincidence could be safely ignored, but in a few the manganese interference was serious, and the correct intensity of *In* 3258 was obtained by working backwards from *In* 3256, using the average intensity ratio for the two lines.

Working curves were constructed, using artificial standards consisting of Johnson-Matthey "Specpure" metal oxides diluted with a "claylike" matrix. This matrix was difficult to prepare because of the omnipresence of lead and copper, but the following mixture was satisfactory after certain precautions were taken: silica (65%), alumina (25%), potassium sulfate (7%), ferric oxide (hydrated) (3%). Concentration steps from 1000 ppm to 3 ppm of Ga, Sn, Li, Cu, Ag, and Pb were prepared by dilution.

Spectral lines used are listed in Table 5 (taken from Harrison, 1939). No serious interference by adjacent lines was experienced.

Precision

The precision of the analytical methods was evaluated from working-curve data and from sample analysis, following the treatment of an analogous statistical problem by Mood (1950, p. 300). Let x_i be the log concentration of a standard which gives log-light intensity y_i, as measured from the densitometry. Suppose n standards were exposed to obtain the working curve $y = \alpha + \beta x$. Then the variance of the y-values is given by

$$\sum_{i=1}^{n} \frac{(y_i - \alpha - \beta x_i)^2}{n-2} = \frac{C}{n-2} \qquad (1).$$

Let y_i' be the light intensity derived for an unknown whose log concentration is x_i' Let

m samples of this material be analyzed. Then the variance of the y_i'-values is

$$\sum_{j=1}^{m} \frac{(y_i' - \bar{y}')}{m-1} = \frac{D}{m-1} \qquad (2),$$

where $\bar{y}'$ is the mean of y_i'-values.

TABLE 6.—ANALYTICAL PRECISION

Element	α_r (for r = 3)	p	p_2
Cr I	0.059	14%	9%
V I	0.090	21	13
V II	0.070	16	
Ni I	0.090	21	14
Co	0.094	21	
Zr	0.095	22	
Sc	0.074	17	
Y	0.069	16	
Sr	0.044	10	
Ba	0.039	9	
Ga	0.030	7	
Sn	0.075	18	
Li	0.031	7	
Cu	0.028	6.5	
Ag	0.022	5	
Pb	0.043	9	

The best estimate of the variance (s_y^2) of all the y-values is obtained from equations (1) and (2) and is

$$s_y^2 = \frac{C + D}{n + m - 3}.$$

The variance of x is s_x^2 and

$$s_x^2 = \frac{s_y^2}{\beta^2}.$$

The quantity s_x is then the standard deviation for the analysis of a single sample. For a sample analyzed r times the standard deviation is $s_r = \frac{s_x}{\sqrt{r}}$, and in most cases $r = 3$. The result of the analysis is k_0, where $\log k_0 = x_0 = (\bar{y}' - \alpha)/\beta$. This treatment assumes that x is normally distributed, so that concentration (k) must have a skew distribution. This is important and will be dealt with later.

To interpret the s_r values, consider the element zirconium with $s_r = 0.095$. If a rock is analyzed and yields $\log k_0 = 2.00$ (corresponding to 100 ppm) then there is a 68 per cent probability that the true value of $\log k_0$ lies between 2.095 and 1.905, or that k_0 lies between 124 and 80. The mean value of k_0 is 102 ppm. The interval corresponding to $\pm s_r$ can be expressed roughly as a percentage of the mean, ±22 per cent, and is designated as p in Table 6. This may not be mathematically sound but gives a clear idea of the precision. The precision is more satisfactory for the second group of elements (Table 6).

Figures are absent for beryllium, lanthanum, and molybdenum because these elements were below the sensitivity limit in most samples. The same applies to the second lines Cr II and Ni II, which can arbitrarily be assigned the same s_r values as Cr I and Ni I respectively. Where an element could be determined from both lines the mean concentration is used with a precision calculated from the mean of the two s_r values divided by $\sqrt{2}$. This quantity (p_2) is indicated in the last column of Table 6.

RESULTS

Statement of Analyses

The analytical results (Tables 7–16) are expressed in parts per million (ppm). In most cases figures could be obtained for Ga, Cr, V, Li, Ni, Co, Cu, Sc, Zr, Y, Sr, and Pb, so this group of elements (arranged in increasing ionic radius) constitutes each table. The symbols *tr* and — indicate *trace* and *spectral line not visible* respectively. For the purposes of calculation numerical values are given to these symbols, and the figures are grouped in footnotes. The sensitivity figures indicate the average lower limit of measurement but vary with each exposure.

Be, Mo, Sn, Ag, and La were sought in every sample, but in only a few cases was the amount determinable. In nearly every case the Ba content was too high for accurate determination by the method used. These elements are not mentioned further in the present paper.

All analyses are given with two significant figures, regardless of whether the figure is near 1 or 1000 ppm. This is logical if it is recalled that the concentration scales in the working curves are logarithmic and that the standard deviations are expressed in the same units.

TABLE 7.—LOW-GRADE SHALES AND SLATES

Sample number / Sensitivity	Ga 5	Cr 5	V 5	Li 35	Ni 3	Co 2	Cu 1	Sc 5	Zr 10	Y 20	Sr 10	Pb 10
L 1	31	86	68	tr.*	64	11	24	11	180	36	110	33
L 2	35	160	150	tr.*	110	21	59	14	190	52	400	—‡
L 3	16	93	81	77	46	10	5.9	9.5	260	41	350	13
L 4	18	48	43	64	44	16	1.5	7.1	200	31	1700‖	15
L 8	27	160	180	85	99	14	17	21	310	68	730	30
L 9	29	150	83	90	72	14	15	9.4	84	33	180	tr.§
L10	26	93	75	83	68	19	18	12	310	50	460	16
L11	19	130	120	48	98	23	22	10	170	40	250	21
L14	23	120	94	—†	85	19	6.8	9.9	210	44	320	—‡

* Taken as 30 ppm for calculation
† Take as 20 ppm for calculation
‡ Taken as 1 ppm for calculation
§ Taken as 9 ppm for calculation
‖ This sample lime-rich, which may explain high Sr content

TABLE 8.—FOUR LOW-GRADE PELITES

Sample number / Sensitivity	Ga 5	Cr 5	V 5	Li 35	Ni 3	Co 2	Su 1	Sc 5	Zr 10	Y 20	Sr 10	Pb 10
L87	14	180	170	—*	95	27	43	15	88	30	1600†	13
L88	11	100	170	50	73	11	36	11	190	30	640	23
L89	13	130	120	58	160	19	31	9.5	140	29	620	20
S66	9	56	61	46	32	14	21	7.2	150	21	900†	14

* Taken as 30 ppm for calculation
† This figure uncertain and is ignored for calculation.

TABLE 9.—AVERAGE COMPOSITION OF ALL LOW-GRADE PELITES

	Four pelites		Nine Littleton shales		All low-grade pelites	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Ga	12	....	25	5.6	20.8	7.5
Cr	117	....	116	35	116	38.7
V	130	....	99	41	109	44.0
Li	46	....	59	25	54.7	22.0
Ni	90	....	76	22	80.5	33.4
Co	18	....	16	4.4	16.8	4.0
Cu	33	....	17	18	23.1	15.5
Sc	10.7	....	12	3.9	11.3	4.3
Zr	142	....	213	67	191	68.0
Y	28	....	44	10	38.8	11.5
Sr	630	....	500	457	524	416.0
Pb	18	....	15	11	16.1	9.3

The rocks are grouped primarily according to whether they are products of low-, medium- or high-grade metamorphism. These three grades, used by Billings and his associates in mapping the rocks, would correspond to all stages from below the lowest green-schist facies to the highest amphibolite facies (Turner, 1948) or, alternatively, all the isograds from below chlorite to sillimanite (Harker, 1939).

Low-grade Rocks

Before searching for any trends it is necessary to find the range of composition in the unmetamorphosed slates and shales and to know whether these Littleton rocks are generally representative of the pelitic facies. Accordingly, several samples of pelitic rocks of widely different age and locality were analyzed for comparison.

The analyses of these rocks appear in Tables 7 and 8, with averages in Table 9. Thirteen rocks were analyzed, of which 9 were shales and slates from the Littleton formation and the others were selected at random from a collec-

tion of pelitic materials. In the Littleton rocks the range of values for most elements is relatively large (Table 7). With copper moreover the range is from 1.5 ppm to more than three times the mean value of 17 ppm, and with strontium there is an unusually high figure of 1700 ppm, nearly four times the average. The sample was lime-rich, and the strontium may be present in carbonate material. These relations are exemplified by the standard deviation (s.d.) figures; in most cases the s.d. is between 20 per cent and 50 per cent of the mean value, but with copper and strontium the s.d. is 100 per cent or more of the mean. There are however no valid reasons for rejecting the single high strontium figure, and it is included in the calculations. The range in composition is believed to be real and valid and not due to experimental inaccuracy (Table 6).

For Cr, V, Li, Ni, Co, Sc, Sr, and Pb (Table 8) the average values are closely similar to the previous group and lie within one s.d. With copper and zirconium there is just about one s.d. difference between the means, while with gallium the average of the four pelites lies more than two s.d.'s from the average of the Littleton slates. It is necessary to test more rigorously whether there are any significant differences between the parent populations from which the two groups of nine and four rocks were drawn. If it is assumed that both parent populations are normally distributed then Student's *t*-test (Mood, 1950, Chap. 9) may be applied to each element.

The results show that for copper the probability of the difference of the means being due to chance is somewhat greater than 0.10. For the difference to be regarded as real or significant the probability should be 0.05 or less. With zirconium there is a little less than 0.10 probability, and with gallium less than 0.01. Hence it is highly improbable that the gallium content of the Littleton formation is representative of pelitic rocks, whereas with copper and zirconium the position is uncertain, and with the remaining elements the Littleton rocks seem well representative of all pelitic rocks. The four random rocks constitute a small sample, and a larger number might change the situation. (It will be seen later that the gallium average for the low-grade slates is not appreciably higher than for medium- and high-grade rocks.)

It is considered reasonable to combine the 13 sample analyses to give an average for low-grade pelitic rocks (Table 9).

Medium-grade Rocks

The question now is to determine whether there is any appreciable difference in composition between the original sedimentary rocks and their metamorphosed equivalents, *i.e.* whether any metasomatism has occurred at the trace-element level. The comparisons take no account of any volume changes suffered by the rocks, since they are based on weight units. That volume changes do take place is indicated by a general increase in the specific gravity of metamorphosed rocks as compared with their parent sedimentary rocks. Metasomatic changes in major constituents will be discussed in a later paper, but it should be noticed here that there are undoubted changes in certain constituents, especially water.

The medium-grade rocks were identified in the field and laboratory as schistose rocks, usually consisting of two micas, quartz, and a little feldspar, and frequently containing chlorite, garnet, staurolite, kyanite, andalusite, and chloritoid. Sillimanite was considered indicative of high-grade metamorphism. Certain assemblages, such as biotite-garnet-quartz, contain no critical index minerals and were therefore classified according to their situation in the field as described by the original quadrangle map sheets, which indicate metamorphic grades. Rocks that have undergone retrogressive changes are classed according to their present mineralogy in the highest grade possible—*e.g.*, a rock carrying both retrograde chlorite and sillimanite-muscovite aggregates is still classed as a high-grade rock.

Table 10 contains the analyses of 20 medium-grade schists; Table 11 contains the averages and s.d. figures, with the low-grade rocks included for comparison. For most elements the range of values resembles closely the low-grade rocks, giving rise to similar average and s.d. figures. Lithium, copper, and lead show some differences. For lithium there are two figures (630 and 500 ppm) well above the range of most

TABLE 10.—MEDIUM-GRADE SCHISTS

Sample number / Sensitivity	Ga 5	Cr 5	V 5	Li 35	Ni 3	Co 2	Cu 1	Sc 5	Zr 10	Y 20	Sr 10	Pb 10
L12	17	110	130	76	38	10	4.4	15	170	31	930	64
L13	13	140	95	61	62	13	9.2	13	460	57	410	26
L28	11	50	86	45	21	11	1.8	8	220	56	1300	tr.‡
L61	20	95	160	110	62	19	85	15	170	57	670	32
L62	30	130	150	630	88	24	31	12	250	47	530	25
L63	20	110	98	97	71	18	8.4	13	300	52	900	23
L64	19	110	140	31	36	14	33	16	200	44	1000	33
L65	5.7	120	110	tr.†	94	40	13	10	210	48	690	tr.‡
L66	20	100	120	58	60	22	32	13	220	39	610	39
L67	9.6	100	110	71	88	20	31	17	250	46	550	16
L69	17	140	150	110	110	31	40	15	290	44	630	29
L70	18	60	100	59	24	14	33	7.8	110	28	560	26
L71	14	60	88	—†	46	20	82	7.6	130	24	340	12
L73	12	200	180	tr.§	61	20	16	16	150	35	1800*	32
L75	14	150	150	tr.‖	97	27	9.5	8.1	220	—†	930	11
L76	14	88	140	66	49	16	10	6.4	150	29	1200	tr.‡
L77	11	100	100	64	68	17	1.1	9.9	300	30	710	12
L82	16	130	110	100	73	18	5.1	8.4	180	27	630	31
L84	23	130	130	500	78	18	4.8	12	150	24	610	21
L86	13	130	160	—†	47	15	26	14	120	29	680	19

* These figures unreliable and are ignored for calculation
† Taken as 10 ppm for calculation
‡ Taken as 5 ppm for calculation
§ Taken as 20 ppm for calculation
‖ Taken as 40 ppm for calculation

TABLE 11.—AVERAGE COMPOSITION OF MEDIUM-GRADE SCHISTS

Element	Medium-grade		Low-grade	
	Mean	S.D.	Mean	S.D.
Ga	15.9	5.14	20.8	7.5
Cr	113	33.5	116	38.7
V	125	27.0	109	44.0
Li	108	157	54.7	22.0
Ni	63.7	23.7	80.5	33.4
Co	19.4	6.74	16.8	4.00
Cu	23.8	23.3	23.1	15.5
Sc	11.9	3.10	11.3	4.30
Zr	213	78.7	191	68.0
Y	37.9	12.6	38.8	11.5
Sr	731	244	524	416
Pb	23.3	13.7	16.1	9.30

rocks, which affect the average slightly and the s.d. considerably. However, the samples concerned (L62 and L84) have otherwise normal composition and mineralogy, and there is no reason to reject the lithium figures. The position is less marked with regard to copper and lead. There are two unusually high figures (85 and 82 ppm) for copper, and in both rocks concerned sulfides are fairly abundant in thin section. With lead there is only one high figure (64 ppm).

With every element except lithium it is clear that there is no significant difference in composition between low- and medium-grade rocks. It is necessary to test further for lithium, and the *t*-test may be applied (modified as in Cochrane and Cox, 1950, p. 92) to examine the difference between the means of low- and medium-grade rocks. The results show that the difference between the means is probably due to chance and is not significant; however, there is a considerable difference between the standard deviations.

In addition to the 20 rocks in Table 10, 4 others were collected for inclusion with the medium-grade rocks (L5, 6, 7, 74 of Table 12).

TABLE 12.—ADDITIONAL MEDIUM-GRADE ROCKS

Sample Number	Ga	Cr	V	Li	Ni	Co	Cu	Sc	Zr	Y	Sr	Pb
L5	17	43	75	tr.	40	21	1.1	12	2400	71	1100	12
L6	98	35	34	47	23	7.7	3.2	12	3100	210	1600	28
L7	6.2	42	6.1	tr.	25	12	11	tr	180	27	120	17
L74	25	10	54	68	8.6	—	3.4	25	370	39	800	30

TABLE 13.—HIGH-GRADE SCHISTS AND GNEISSES

Sample number / Sensitivity	Ga 5	Cr 5	V 5	Li 35	Ni 3	Co 2	Cu 1	Sc 5	Zr 10	Y 20	Sr 10	Pb 10
L18	11	190	260	81	66	37	0.9	45	280	140	560	tr.†
L20	20	120	120	120	110	26	0.9	16	280	54	610	tr.**
L27	11	130	120	91	58	23	1.4	9.7	150	37	400	31
L29	21	130	130	160	85	22	6.9	18	260	71	1400*	32
L31	11	110	79	76	49	10	2.0	9.0	190	39	840	26
L32	17	180	140	83	55	17	1.7	20	190	62	740	21
L33	12	88	110	97	20	13	5.4	51	170	120	1000	14
L38	27	130	180	120	65	18	6.3	20	210	65	1000	26
L39	14	46	110	38	8.7	8.5	12	12	78	57	1600*	37
L40	15	120	110	170	54	14	2.3	13	150	46	1400*	61
L41	20	110	120	69	67	27	19	17	140	50	1100	31
L42	27	110	100	190	68	19	2.6	16	200	51	380	31
L43	18	77	71	140	22	12	15	16	270	49	1300	37
L44	22	140	150	140	77	18	7.8	19	170	67	790	25
L45	21	140	180	190	66	19	7.4	17	140	49	1100	26
L46	33	120	130	270	71	16	4.8	16	130	51	1000	30
L48	22	83	110	310	63	17	6.4	14	220	44	790	31
L49	20	120	81	250	64	16	12	7.7	140	40	360	24
L50	13	100	110	190	61	15	8.6	14	160	47	700	23
L53	21	100	130	100	57	17	9.8	12	170	35	850	31
L54	22	80	71	120	54	18	1.7	14	350	45	1100	29
L55	28	120	140	70	34	21	22	18	200	55	1200	20
L56	18	76	110	59	31	14	37	12	330	55	760	22
L57	23	130	71	48	69	18	5.9	10	250	38	680	38
L58	31	94	110	120	75	24	14	11	220	43	410	tr.†
L68	27	62	100	91	54	19	42	10	170	26	340	30
L78	18	87	86	200	57	16	9.5	5.6	180	23	430	31
L79	13	130	150	76	65	20	31	8.4	380	32	480	17
L80	21	81	130	81	45	21	36	8.4	150	28	870	41
L81	16	78	100	65	52	21	43	9.5	170	33	730	33

* These figures unreliable, ignored for calculation
† Taken as 5 ppm for calculation
** Taken as 10 ppm for calculation

All show considerable anomalies in composition; the only one common to all is the scarcity of chromium, vanadium, and nickel. Other anomalies include high zirconium in L5 and 6, high gallium in L6, and low cobalt in L74. Sample L7 was clearly an impure quartzite, and probably the quartz dilutes Ga, Cr, V, Li, and Ni, whose presence in greater quantities characterizes the pelitic facies. Samples L5 and L74 may be similar, with feldspar present in addition in L74. Sample L6 is the only rock collected which contained abundant chloritoid. Presumably there are sufficient differences from the ordinary schists in the major elements also

(as well as the minor ones) to allow this mineral to form.

TABLE 14.—AVERAGE COMPOSITION OF HIGH-GRADE ROCKS

Element	High-grade		Low-grade	
	Mean	S.D.	Mean	S.D.
Ga	19.8	5.84	20.8	7.50
Cr	109	31.2	116	38.7
V	120	38.0	109	44.0
Li	127	67.0	54.7	22.0
Ni	57.4	19.8	80.5	33.4
Co	18.0	7.01	16.8	4.00
Cu	12.5	12.5	23.1	15.5
Sc	15.6	9.56	11.3	4.30
Zr	203	69.3	191	68.0
Y	51.7	24.2	38.8	11.5
Sr	760	260	524	416
Pb	27.3	10.7	16.1	9.30

lead, however, there are appreciable differences between the means (in terms of standard deviations), and discrimination tests are necessary. With lead and copper the usual t test can be applied, but for lithium and nickel the modified t test is necessary (Cochrane and Cox, 1950, p. 92). The results show that for nickel and copper there is a probability of between 0.05 and 0.01 that the difference in the mean values is due to chance, whereas for lithium and lead the probability is less than 0.005. Examining the individual analyses in Table 13 it is seen that these circumstances have not arisen as a result of a few analyses deviating widely from the mean but are a true expression of the grouping of the figures. The only analysis deviating widely is the nickel figure of 8.7 ppm for L39, and this is only 1 sample in 30. It is concluded that there are genuine, though small, differences in composition between low- and high-grade rocks for lithium, nickel, copper, and lead.

TABLE 15.—AVERAGE COMPOSITION OF LOW-, MEDIUM-, AND HIGH-GRADE ROCKS

Element	Low-grade	Medium-grade	High-grade	Final average	Final S.D.	Number of rocks	Final average (rounded off)
Ga	20.8	15.9	19.8	18.8	6.34	63	19
Cr	116	113	109	112	33.1	63	110
V	109	125	120	119	38.5	63	120
Li	54.7	108	127	106	104	63	110
Ni	80.5	63.7	57.4	64.2	25.5	63	64
Co	16.8	19.4	18.0	18.2	6.59	63	18
Cu	23.1	23.8	12.5	18.3	18.0	63	18
Sc	11.3	11.9	15.6	13.5	7.35	63	14
Zr	191	213	203	204	72.7	63	200
Y	38.8	37.9	51.7	44.7	20.0	63	45
Sr	524	731	760	705	310	57	710
Pb	16.1	23.3	27.3	23.7	12.3	63	24

High-grade Rocks

As mentioned earlier, sillimanite was considered diagnostic of high-grade rocks, although some rocks in which this mineral was absent are grouped here because of field relations. A practical difficulty arose in sampling the banded gneisses, and they are excluded from discussion here.

Table 13 contains the analyses of 30 high-grade schists and gneisses and Table 14 contains the average and S.D. values, with those for the low-grade rocks included for comparison. In general the results are similar for most elements. For lithium, nickel, copper, and

Lithium is the only element for which both the medium- and high-grade rocks differ from low-grade ones. Application of the modified t test shows that the difference in means is not significant, and therefore both groups of rocks may have the same lithium content.

Average Composition and Trends

There are no extreme differences in composition for any of the groups averaged. It is therefore permissible to calculate a grand average, which is presented in Table 15. Each

element is discussed individually in Part II, but some remarks on the overall composition are appropriate here.

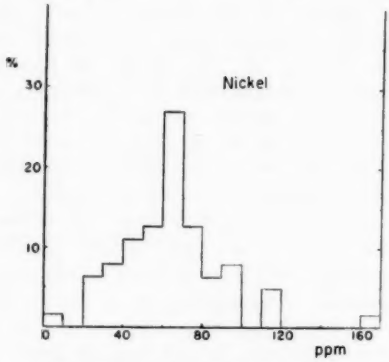

FIGURE 1.—HISTOGRAM FOR NICKEL
Showing the range in the nickel content of 63 shales, schists, and gneisses.

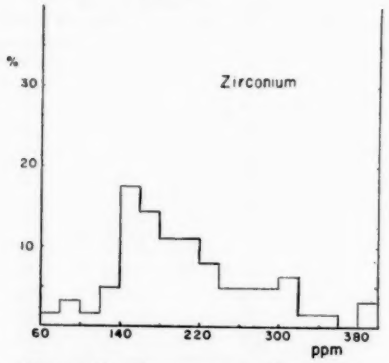

FIGURE 2.—HISTOGRAM FOR ZIRCONIUM
Showing the range in zirconium content of 63 shales, schists, and gneisses.

All the statistical tests have been based on the assumption that the samples were drawn from populations which are normally distributed. Histograms were plotted for each element (Figs. 1, 2). Nickel exhibits one of the most regular histograms, zirconium one of the least regular. In all cases but one there is a strong tendency toward unimodal character, and secondary peaks are probably due to chance. This in itself does not prove a normally distributed population, but makes it unlikely that the averages of numerous individual analyses depart appreciably from normality. Copper shows the most irregular distribution, and little confidence can be placed in any statistical tests applied to it.

The principal composition change during the metamorphism of pelitic sedimentary rocks is a loss of water, to the extent of 3–5 per cent of the rock by weight. Metallic elements would therefore increase by a corresponding amount, apart from any other changes. The increase however would not be apparent for trace elements without very high analytical precision and is in any case masked by the range in original composition. This range is fairly large in proportion to the mean values, as is seen from the standard deviations. Thus, for chromium, which has the lowest s.d. in proportion to the mean, there is a probability of 0.95 that any subsequent analysis will lie within 46–178 ppm, corresponding to the mean ± 2 s.d. That is, 1 analysis in 20 may lie outside this range. However, if another 63 analyses were made and the average taken, the standard deviation must be divided by $\sqrt{63}$, and the range becomes 104–120 ppm. There would be 1 chance in 20 that the average would lie outside this range. For this reason, a difference between averages may be significant even when small, provided the t test is applied. Only with the four elements lithium, nickel, copper, and lead is there any evidence of change.

In the case of lithium and lead there is a small increase accompanying progressive metamorphism. With both metals the statistical tests are conclusive only when the low- and high-grade rocks are compared. Nickel shows a decrease during metamorphism, but this is not well marked. Copper shows a constant value up to medium-grade metamorphism, followed by a small but clear decrease in the highest grade. For the other elements, any apparent trend (*e.g.* strontium) has arisen by chance and is disregarded.

In spite of the evidence, it is doubtful whether the trend for copper is real. The analyses show considerable scatter, as evidenced by the large standard deviation compared to the mean, and a high copper analysis seems always to accompany the presence of sulfides in thin section. These sulfides are probably in part the result of simple metamorphism, in part the result of

local precipitation by solutions. If the trend is real, however, it is interesting to speculate found if the range in composition of the original sediments had not first been deter-

TABLE 16.—COMPOSITION OF BANDED GNEISSES

Sample number	Ga	Cr	V	Li	Ni	Co	Cu	Sc	Zr	Y	Sr	Pb
L25 (mafic)	19	130	210	170	100	33	30	22	400	61	940	11
L26 (felsic)	10	12	43	38	10	7	4.4	6.2	110	55	1580*	33
Average L25, L26	15	71	127	104	55	20	17.2	14.1	260	58	1260	22
L36a (mafic)	33	170	140	330	72	16	5.8	21	240	43	590	tr.†
L36b (felsic)	9	50	52	74	25	11	1.3	7.1	130	44	1700	29
Average L36a, L36b	21	110	96	202	49	14	3.6	14.0	185	44	1095	17

* This figure uncertain
† Taken as 5 ppm

where the copper has gone, after its 50 per cent elimination during the peak of metamorphism.

In the case of lithium and lead the concentrations of these two elements have nearly doubled during metamorphism. It is evident that the elements have been introduced from outside. Billings (1937b) has shown how potash has been introduced into certain high-grade schists in New Hampshire where sillimanite has been replaced by muscovite. Many high-grade schists in the present work are similar rocks. Probably therefore the solutions which introduced potash also introduced lead and lithium, although in much smaller amounts. Lead and potassium have ions of similar size, whose association in silicate minerals is well known, and the lead is probably camouflaged in the muscovite formed by the introduction of potassium. Lithium may also have gone into the same mineral, but to a different structural position. Both elements are enriched in the residual solutions from the formation of granite, which is consistent with Billings' hypothesis that the solutions introducing potash were derived from near-by bodies of Kinsman quartz monzonite or Bickford granite. It will be necessary to investigate by mineral analysis the hypothesis that the lithium and lead are located in the muscovite.

It should be emphasized that the trends which have been discussed could not have been mined. Metasomatism cannot be demonstrated without first establishing the extent of variation of the original rock.

Banded Gneisses

The composition of two banded gneisses is given in Table 16. The first comprises L25 and L26, which are the dark and light layers respectively, as much as they could be separated from each other. L25 is rich in biotite and contains sodic plagioclase, quartz, and a little apatite. L26 is more felsic, containing oligoclase and quartz with minor biotite and muscovite. The pair L36a and 36b are similar to L25 and L26, except that the mafic member in L36a and 36b is rich in opaque minerals, chiefly graphite.

The difference in composition between the light and dark bands in both cases is similar and can be explained on the basis of the mineralogy. Thus the higher concentration of Cr, V, Li, Ni, Co, Cu, Sc, and Zr in the dark bands follows from the abundance of biotite. All these elements are readily accommodated in the mica structure, with the possible exception of zirconium which may be present in zircon. There is some indication that gallium is to a slight degree also concentrated in biotite. By contrast the lighter bands are richer in strontium and lead. Strontium is

presumably located in the feldspar, and the lead in the white mica (microcline is absent).

The banded gneisses seem to be made up of roughly equal proportions of light and dark layers. Accordingly the average compositions are indicated in Table 16 but should be considered as uncertain, since the rocks are so heterogeneous. Nevertheless it is interesting to compare the figures with the average for all the nonbanded rocks in Table 15 and to note the close correspondence for all elements except chromium and strontium (L25, 26) and lithium, copper, and strontium (L36a, 36b). To the writer this seems proof that these gneisses are the products of metamorphic differentiation rather than injection of material from outside.

Conclusions

Statistical study of the variation in the trace-element content of pelitic rocks during regional metamorphism indicates that the considerable range in composition of the parent rocks makes it difficult to discover any clear trends. However, nickel, copper, lithium, and lead show variations due to metamorphism significantly different from the initial range. Nickel and copper have a poorly defined tendency to decrease, whereas lithium and lead show increases of the order of 100 per cent compared to the low-grade rocks, these being correlated with a potash metasomatism previously described by Billings. Other elements show no detectable change.

The analyses of a few banded gneisses or migmatites suggest that these rocks have developed by metamorphic differentiation rather than magmatic injection, although the evidence is not conclusive.

Comparison with other pelitic rocks will be made in Part II. The variation in major constituents is being studied by gravimetric and modal analysis. The statistical methods used in this paper are fully explained elsewhere (Shaw and Bankier, 1954).

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McMaster University, Hamilton, Ontario

Manuscript Received by the Secretary of the Society June 15, 1953

Project Grant 566/51/52

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 65, PP. 1167-1182, 11 FIGS. DECEMBER 1954

TRACE ELEMENTS IN PELITIC ROCKS

PART II: GEOCHEMICAL RELATIONS

BY DENIS M. SHAW

ABSTRACT

The range in composition of pelitic shales, schists, and gneisses has been investigated for a number of trace elements and has been compared with previous work on similar materials. An interesting distribution law has appeared (logarithmic), namely that the range in composition extends from zero to about twice the mean value for almost every element. The probability that a rock will fall outside this range is low.

Fairly good positive correlation has been found between chromium, vanadium, and nickel, with cobalt participating to some extent. All these elements tend to be high or low together, but the most regular correlation is between nickel and chromium.

In general, the content of the trace elements studied is what would be expected from erosion and transfer from the average igneous rock, with no loss or gain on the way. Copper is an exception with a clear loss, whereas lithium and strontium show an increase.

Comparison with suites of silicic and basic igneous rocks emphasizes some differences between these and pelitic rocks, but also shows that in many cases the composition fields overlap extensively. Certain revisions in crustal abundance (average igneous rock) figures are suggested.

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Introduction

Preliminary

In Part I (Shaw, 1954) the writer presents the results of the analysis of numerous shales, schists, and gneisses, representing the original and metamorphosed sediments of the Devonian Littleton formation of New Hampshire. The following elements were determined spectrographically: Be, Ga, Cr, V, Sr, Mo, Li, Ni, Co, Cu, Sc, Zr, Y, Ag, La, Sr, Pb, Ba. The averages and standard deviations were calculated for all these elements, except Be, Sr, Mo, Ag, La, and Ba. Of the last group the first five were usually too low, and Ba too high, to be determined by the methods used.

Part I was concerned mainly with reporting the methods used and the results, and with trying to establish whether any variation in concentration of minor elements occurred during metamorphism. The wide range in initial composition made such changes difficult to see, but a clear-cut increase in Li and Pb was found, as well as a less well-defined decrease in Ni and Cu. With most elements, however, the concentration remained about the same during metamorphism.

Part II is concerned with the original composition of the sediments and the geochemical relationships among their trace elements.

Acknowledgments

The work was made possible by generous grants from the National Research Council of Canada, the Geological Survey of Canada, and the Penrose Bequest of The Geological Society of America, to whom the writer is much indebted. Some of the analyses of White Mountain granites were carried out by G. R. Webber. J. Capel assisted with many calculations and with the preparation of diagrams.

Geochemical Relations in Pelitic Rocks

Statement of Analyses

The results of the analyses recorded in Part I (Shaw, 1954) are recapitulated in Table 1, showing the averages and standard deviations for 63 rocks, their localities, and figures for the analytical precision and sensitivity. The calculated averages are given to three figures, irrespective of the magnitude of the result; this is consistent with the logarithmic results obtained with the spectrograph. The last figure of the three is meaningless, insofar as the analytical methods are concerned, but is retained in all calculations until the final statements are made.

Table 1.—Averages and Standard Deviations for 63 Rocks of Littleton Formation

(In ppm)

Element	Calculated average	Average (rounded off)	Standard deviation (s.d.)	Ratio s.d. to average, as percentage
Ga	18.8	19	6.34	34
Cr	112	110	33.1	29
V	119	120	38.5	32
Li	106	110	104	98
Ni	64.2	64	25.5	40
Co	18.2	18	6.59	36
Cu	18.3	18	18.0	98
Sc	13.5	14	7.35	54
Zr	204	200	72.7	36
Y	44.7	45	20.0	45
Sr	705	710	310	44
Pb	23.7	24	12.3	52

This is common and good practice in statistics. Of the 63 rocks analyzed all but 4 were from the Littleton formation. The remaining four were chosen at random from the university collections and were all pelitic. They were similar in composition to the Littleton rocks and so are included in the averages.

Comparison with Other Pelitic Rocks

It is of interest to know whether the Littleton rocks may be considered "typical" of the pelitic facies, insofar as minor elements are concerned. Owing to the lack of precise data this question cannot be completely resolved, but a comparison can be made with the available data.

Most available figures come from studies of individual elements and are semiquantitative. It is pointless to carry out any statistical tests on such figures, which may be in error by one order of magnitude. Averages are calculated in a few cases, but only for convenience. In a few papers there are determinations on numerous elements. Thus Nockolds and Mitchell (1948, p. 545) give analyses of 11 Scottish schists and hornfelses, Nos. 1–11. These are pelitic rocks

except for No. 6, which is omitted from further discussion. Sahama (1945, p. 38–39) records analyses of six schists (A–F) from the Pre-

those of Nockolds and Mitchell (1948) and Goldschmidt and Peters (1931a). The schists analyzed by Sahama (1945) appear surprisingly

TABLE 2.—GALLIUM IN SHALES, SCHISTS, GNEISSES

Material	Reference	Number of samples	Gallium			
			Min.	Max.	Av.	S.D.
Shale, schist, and gneiss	Shaw (1954)	63	5.7	35	19	6.3
Schist, hornfels	Nockolds and Mitchell (1948)	10	10	25	18	...
Schist	Sahama (1945)	6	74	220	104	...
Russian clay	Borovick, Prokopenko, and Pokrovskaya (1939) (composite sample)	(16)	...	...	50	...
Kaolin	Goldschmidt and Peters (1931a)	.....	...	...	7	...
Red clay	Goldschmidt and Peters (1931a)	.....	...	...	15	...
Bauxite	Goldschmidt and Peters (1931a)	.....	...	...	22	...
Bauxite	Gordon and Murata (1952)	14	50	100	80	...
Siliceous- and alum-shale	Leutwein (1951)	63	0	300	59	...

TABLE 3.—CHROMIUM IN SHALES, SCHISTS, GNEISSES

Material	Reference	Number of samples	Chromium			
			Min.	Max.	Av.	S.D.
Shale, schist, and gneiss	Shaw (1954)	63	48	190	110	33.1
Schist, hornfels	Nockolds and Mitchell (1948)	10	30	600	170	....
Schist	Sahama (1945)	6	136	2100	590	....
Phyllite	Goldschmidt (1937a) (composite sample)	(18)	...	....	140	....
Clay, etc.	Lundegårdh (1949)	63	1	30	8	....
Bauxite	Gordon and Murata (1952)	14	20	300	110	....
Siliceous- and alum-shale	Leutwein (1951)	128	0	220	40	....
Mississippi silt	Clarke (1924) (composite sample)	(235)	...	....	68	....
Terrigenous mud	Clarke (1924) (composite sample)	(52)	...	....	340	....
Red clay	Clarke (1924) (composite sample)	(51)	...	....	82	....

cambrian of Finnish Lapland. Leutwein (1951) gives numerous analyses for various elements in the alum- and siliceous-shales of Thuringia. Other figures are available in papers by Clarke, Goldschmidt, and others.

Tables 2–13 present the data found for each element, and the results from the Littleton Formation. Each element will now be considered individually.

GALLIUM (TABLE 2): The results of the present work are of the same order of magnitude as

rich in gallium, if the results are reliable. The data for bauxites show an enrichment in gallium for these rocks, as compared to marine argillaceous sediments.

CHROMIUM (TABLE 3): Most figures given in Table 3 agree with the present results. The results of Sahama (1945), however, are considerably higher, as is the terrigenous mud quoted by Clarke (1924). On the other hand the results of Lundegårdh (1949) are notably lower, which may be due to an abundance of quartz in the

rocks. In any event the present results seem typical for most argillaceous rocks.

VANADIUM (TABLE 4): The present results agree with most of the other figures and may be considered typical for normal pelitic sediments. The composite samples quoted by Clarke (1924) show higher values but give no idea of the experimental error or the range in composition. Some of the rocks analyzed by Leutwein (1951) are rich in vanadium (and were in fact investigated for this reason) but are the products of unusual conditions of sedimentation. The bauxites studied by Gordon and Murata (1952) contain about the same amount of vanadium as pelitic rocks although the single bauxite analyzed by Jost (1932) is much richer.

TABLE 4.—VANADIUM IN SHALES, SCHISTS, GNEISSES

Material	Reference	Number of samples	Vanadium			
			Min.	Max.	Av.	S.D.
Shale, schist, and gneiss	Shaw (1954)	63	43	260	120	38.5
Schist, hornfels	Nockolds and Mitchell (1948)	10	40	250	82	....
Schist	Sahama (1945)	6	5.6	56	32	....
Clay, shale	Jost (1932)	17	90	150	120	....
Bauxite	Jost (1932)	1			600	....
Bauxite	Gordon and Murata (1952)	14	40	200	92	....
Siliceous- and alum-shale	Leutwein (1951)	180	10	2000	670	....
Mississippi silt	Clarke (1924) (composite sample)	(235)	....	....	136	....
Terrigenous mud	Clarke (1924) (composite sample)	(52)	....	....	200	....
Red clay	Clarke (1924) (composite sample)	(51)	....	....	240	....

TABLE 5.—LITHIUM IN SHALES, SCHISTS, GNEISSES

Material	Reference	Number of samples	Lithium			
			Min.	Max.	Av.	S.D.
Shale, schist, and gneiss	Shaw (1954)	63	10	630	106	104
Shale only	Shaw (1954)	13	20	90	55	22
Schist, hornfels	Nockolds and Mitchell (1948)	10	8	70	41	...
Schist	Sahama (1945)	6	4.7	47	27	...
Shale	Strock (1936)			...	46	...
Red Clay	Strock (1936)	1	....	...	78	

LITHIUM (TABLE 5): Few analyses of lithium in shales are available, and the results of the present work show a high average compared with the results of Nockolds and Mitchell (1948), Sahama (1945), and Strock (1936). However, the standard deviation (s.d.) is also high, indicating a considerable range in composition. The present results indicate a metasomatic increase of lithium in the higher grades of metamorphism (Part I). If, instead of averaging all the rocks, the results for the low-grade shales alone are considered, these rocks are in closer agreement with the other writers.

NICKEL (TABLE 6): On the whole the present results may be considered typical for nickel, although there are considerable differences with different authors. The deep-sea clays are fairly rich in nickel, while the residual bauxites have had most of their nickel removed by transportation.

COBALT (TABLE 7): The cobalt content of the present rocks agrees with other argillaceous sediments, as far as can be seen from the limited data. The cobalt content of bauxites is lower in a similar way to nickel.

COPPER (TABLE 8): The copper content of the

TABLE 6.—NICKEL IN SHALES, SCHISTS, GNEISSES

Material	Reference	Number of samples	Nickel			
			Min.	Max.	Av.	S.D.
Shale, schist, and gneiss	Shaw (1954)	63	8.7	160	64	25.5
Schist, hornfels	Nockolds and Mitchell (1948)	10	10	70	27	....
Schist	Sahama (1945)	6	2.4	24	17	....
Clay, etc.	Lundegårdh (1949)	63	<2	150	42	....
Clay, ooze	Petterson and Rotschi (1952)	11	31	440	160	....
Mississippi silt	Clarke (1924) (composite sample)	(235)	.....	...	134	....
Bauxite	Gordon and Murata (1952)	14	0	50	6.4	....
Siliceous- and alum-shale	Leutwein (1951)	133	0	500	70	....

TABLE 7.—COBALT IN SHALES, SCHISTS, GNEISSES

Material	Reference	Number of samples	Cobalt			
			Min.	Max.	Av.	S.D.
Shale, schist, and gneiss	Shaw (1954)	63	8.5	40	18	6.59
Schist, hornfels	Nockolds and Mitchell (1948)	10	3	30	12	....
Schist	Sahama (1945)	6	0	7.9	6.6	....
Clay, etc.	Lundegårdh (1949)	63	<1	80	21	....
Bauxite	Gordon and Murata (1952)	14	0	20	1.4	....
Siliceous- and alum-shale	Leutwein (1951)	9	0	20	11	....

TABLE 8.—COPPER IN SHALES, SCHISTS, GNEISSES

Material	Reference	Number of samples	Copper			
			Min.	Max.	Av.	S.D.
Shale, schist, and gneiss	Shaw (1954)	63	0.9	85	18.3	18.0
Schist, hornfels	Nockolds and Mitchell (1948)	6	20	150	43	....
Mississippi silt	Clarke (1924) (composite sample)	(235)	....	...	34	....
Terrigenous clay	Clarke (1924) (composite sample)	(52)	....	...	128	....
Red clay	Clarke (1924) (composite sample)	(51)	....	...	190	....
Terrigenous mud	Siebenthal (1915) (in Rankama and Sahama, 1950, p. 700)	.....	....	...	7	....
Argillaceous sediments	Carobbi and Pieruccini (1943) (in Rankama and Sahama, 1950, p. 700)	.....	....	...	192	....
Bauxite	Gordon and Murata (1952)	14	0	30	14	....
Siliceous- and alum-shale	Leutwein (1951)	106	0	800	50	....

present rocks is variable; the s.d. is nearly equal to the average. Figures taken from the literature vary considerably. Copper conplay an important part in determining this behavior. The present figure for copper is retained, for want of a better.

TABLE 9.—SCANDIUM IN SHALES, SCHISTS, GNEISSES

Material	Reference	Number of samples	Scandium			
			Min.	Max.	Av.	S.D.
Shale, schist, and gneiss	Shaw (1954)	63	5.6	51	13.5	7.35
Schist, hornfels	Nockolds and Mitchell (1948)	10	0	30	....	....
Schist	Sahama (1945)	6	0.7	20	6.5	....
Terrigenous mud	Goldschmidt and Peters (1931b)	.....	...	..	3	....
Red clay	Goldschmidt and Peters (1931b)	.....	...	..	4.6	....
Bauxite	Gordon and Murata (1952)	14	4	10	6.9	....

TABLE 10.—ZIRCONIUM IN SHALES, SCHISTS, GNEISSES

Material	Reference	Number of samples	Zirconium			
			Min.	Max.	Av.	S.D.
Shale, schist, and gniiss	Shaw (1954)	63	78	460	204	72.7
Schist, hornfels	Nockolds and Mitchell (1948)	10	150	800	365	....
Schist	Sahama (1945)	6	0	740	209	....
Shale, phyllite	Hevesy and Würstlin (1934a) (*in* Rankama and Sahama, 1900, p. 567)	....	...	....	120	....
Red clay	Hevesy and Würstlin (1934a) (*in* Rankama and Sahama, 1950, p. 567)	....	...	....	140	....
Bauxite	Hevesy and Würstlin (1934a) (*in* Rankama and Sahama, 1950, p. 567)	....	500	900		
Bauxite	Gordon and Murata (1952)	14	800	2000	1300	....
Siliceous- and alum-shale	Leutwein (1951)	19	0	59	24	....

tamination is difficult to avoid in most methods of analysis, unless considerable care is taken; the writer attaches more significance to low than to high values. Nevertheless it does not seem profitable to decide on an average copper content for these rocks at the present time. The range extends from less than 1 to over 200 ppm, and histograms show no regular distribution pattern for this element. A similar erratic distribution of values was noticed previously (Shaw, 1951) for indium, another strongly chalcophile element in igneous rocks. In both cases the chalcophile character is believed to

SCANDIUM (TABLE 9): The scandium content of argillaceous sediments seems well represented by the present rocks, so far as can be ascertained from the meager literature on this element.

ZIRCONIUM (TABLE 10): The present rocks seem typical of pelitic materials so far as zirconium is concerned. A considerable enrichment is noted in the bauxites, probably because of the resistance of zircon crystals to erosion.

YTTRIUM (TABLE 11): The present rocks appear richer in yttrium than others. This may be illusory, since the analytical results were

subject to a possible error owing to the coincidence of a weak manganese line with the line Y4374Å (Part I). The average yttrium content of pelitic sediments is therefore uncertain.

show a clear enrichment in lead, which is reflected in the higher average for all the rocks.

Thus in most cases the results of the present study may be considered representative of all

TABLE 11.—YTTRIUM IN SHALES, SCHISTS, GNEISSES

Material	Reference	Number of samples	Yttrium			
			Min.	Max.	Av.	S.D.
Shale, schist, and gneiss	Shaw (1954)	63	10	140	44.7	20.0
Schist, hornfels	Nockolds and Mitchell (1948)	10	0	50	.....	....
Schist	Sahama (1945)	6	0	24	9.1	....
Terrigenous mud	Goldschmidt and Peters (1931b)	....	..	...	0	....
Red clay	Goldschmidt and Peters (1931b)	....	..	...	<8	....
Bauxite	Goldschmidt and Peters (1931b)	....	..	...	<8	....
Bauxite	Gordon and Murata (1952)	14	40	400	150	....
Siliceous- and alum-shale	Leutwein (1951)	19	0	390	54	....

TABLE 12.—STRONTIUM IN SHALES, SCHISTS, GNEISSES

Material	Reference	Number of samples	Strontium			
			Min.	Max.	Av.	S.D.
Shale, schist, and gneiss	Shaw (1954)	57	110	1700	710	310
Schist, hornfels	Nockolds and Mitchell (1948)	10	100	2000	850	...
Schist	Sahama (1945)	6	0	240	...	...
Shale	Noll (1934) (composite sample)	....	...	....	170	...
Shale, phyllite	Hevesy and Würstlin (1934b) (*in* Rankama and Sahama, 1950, p. 482)	....	...	....	20	...
Red clay	Hevesy and Würstlin (1934b) (*in* Rankama and Sahama, 1950, p. 482)	....	...	....	60	...
Bauxite	Gordon and Murata (1952)	14	4	900	190	...
Siliceous- and alum-shale	Leutwein (1951)	49	10	300	82	...
Terrigenous clay	Clarke (1924) (composite sample)	(52)			470	...
Red clay	Clarke (1924) (composite sample)	(51)			250	...

STRONTIUM (TABLE 12): The present results are representative of all argillaceous sediments. Most earlier results are lower, but several seem much too low. The results of Nockolds and Mitchell (1948) are similar to the present analyses.

LEAD (TABLE 13): This element is present in small quantities in pelitic rocks, and the results for low-grade shales may be considered representative. As with lithium, the high-grade rocks pelitic rocks. In the case of lithium and lead the averages in Table 1 are rather high, and the averages for the low-grade rocks alone are more representative. There is some analytical uncertainty concerning yttrium, and this element is not considered further.

Range in Composition

The range in composition of pelitic rocks is indicated by the standard deviations in Table

TABLE 13.—LEAD IN SHALES, SCHISTS, GNEISSES

Material	Reference	Number of samples	Lead			
			Min.	Max.	Av.	S.D.
Shale, schist, and gneiss	Shaw (1954)	63	1	64	23.7	12.3
Shale only	Shaw (1954)	13	1	33	16.1	9.3
Schist, hornfels	Nockolds and Mitchell (1948)	10	0	<10	.....	....
Schist	Sahama (1945)	6	0	<9	.....	....
Resistates, hydrolysates	Goldschmidt (1937a)				20	....
Bauxite	Gordon and Murata (1952)	14	0	70	6.7	....
Siliceous- and alum-shale	Leutwein (1951)	14	0	1000	176	....
Mississippi silt	Clarke (1924) (composite sample)	(235)	...	....	2	....
Terrigenous clay	Clarke (1924) (composite sample)	(52)	...	....	3.7	....
Red clay	Clarke (1924) (composite sample)	(51)	...	....	74	....

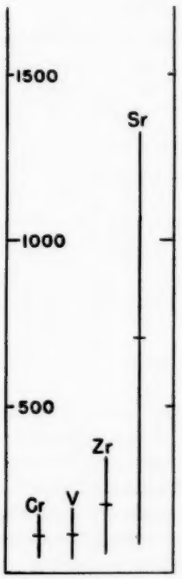

FIG. 1

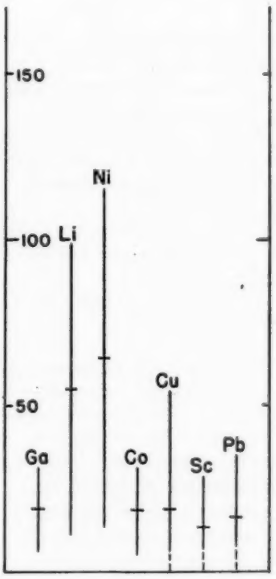

FIG. 2

FIGURE 1.—RANGE IN COMPOSITION OF PELITIC SEDIMENTS FOR 95 PER CENT PROBABILITY: Cr, V, Zr, Sr
FIGURE 2.—RANGE IN COMPOSITION OF PELITIC SEDIMENTS FOR 95 PER CENT PROBABILITY: Ga, Li, Ni, Co, Cu, Sc, Pb

l (the relevant figures for Li and Pb in low-grade shales alone are 22 and 9.3 ppm respectively). Figures 1 and 2 illustrate the ranges into which 95 per cent of pelitic rocks would be expected to fall (*i.e.*, $m \pm 2s$). In other

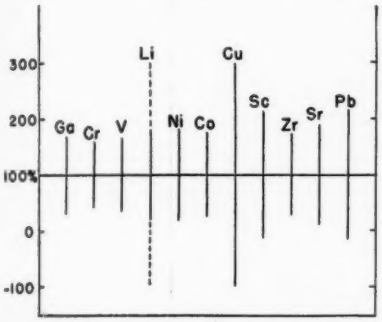

FIGURE 3.—COMPOSITION RANGES FOR 95 PER CENT PROBABILITY EXPRESSED AS PERCENTAGE OF THE MEAN

words, there is little probability that a shale would contain less than 6 and more than 32 ppm Ga. This assumes normally distributed values, which in most cases is a reasonable assumption; this point has been discussed elsewhere (Shaw and Bankier, 1954). However, the ranges differ greatly for each element. In Figure 3 these ranges are expressed as percentages of the mean; except for lithium and copper the relative ranges are about the same, extending from about zero to twice the mean. Lithium falls into the same pattern if the low-grade rocks are considered alone. Copper does not appear to be regularly distributed. Similarly, the ranges are of the same order of magnitude when plotted in ppm on a logarithmic scale. This is, of course, expectable on empirical grounds. Thus, if most shales contain about 700 ppm strontium, one might expect a few to contain about 1400 ppm; but if most shales contain about 19 ppm gallium, it would be unusual to find any containing 1400 ppm, because shales are the product of physical-chemical laws operating between certain limits (*i.e.*, a sedimentary facies) and are statistically homogeneous. Random fluctuations in composition may then be expected, but with lower probability for high fluctuations from the average.

Enrichment and Impoverishment

It is of interest to know which elements have been concentrated and which attenuated during pelitic deposition. In Column 2 of Table 14 are the abundance figures for pelitic rocks, and in

TABLE 14.—CRUSTAL ABUNDANCE OF ELEMENTS COMPARED WITH THEIR ABUNDANCE IN PELITIC SEDIMENTS

Element	Abundance in pelitic sediments	Crustal abundance	Enrichment factor
Ga	19	20	1.0
Cr	110	100	1.1
V	120	100	1.2
Li	55	20	2.8
Ni	64	80	0.8
Co	18	23	0.8
Cu	18	70	0.3
Sc	14	15	0.9
Zr	200	220	0.9
Sr	710	300	2.4
Pb	16	10	1.6

Column 3 are the crustal abundances, taken from Rankama and Sahama (1950, Table 2.3) but in part modified, as indicated later. These crustal abundances cannot be regarded as well substantiated but should be of the right order of magnitude. The last column gives the ratio of the figures in Columns 2 and 3 and indicates whether an element is concentrated or diluted in shales, as compared with the crust as a whole. With most elements there is little change at all; only two ratios are appreciably greater than unity. The first is lithium, whose probable enrichment in hydrolysates has been predicted previously (Rankama and Sahama, 1950, p. 428). Strontium also shows a notable concentration. This has not hitherto been recorded (Rankama and Sahama, 1950, p. 483). The only element showing a notable dilution is copper, this again being contrary to previous belief (Rankama and Sahama, 1950, Table 5.52).

Of the 11 elements studied, 7 have ionic potentials such that one expects them to be deposited in argillaceous (hydrolysate) sediments during gradation: these are Ga, Cr, V, Ni, Co,

Sc, and Zr. The other four—Li, Cu, Sr, Pb—probably go into solution as soluble cations and become trapped in the clay sediments by sorption.

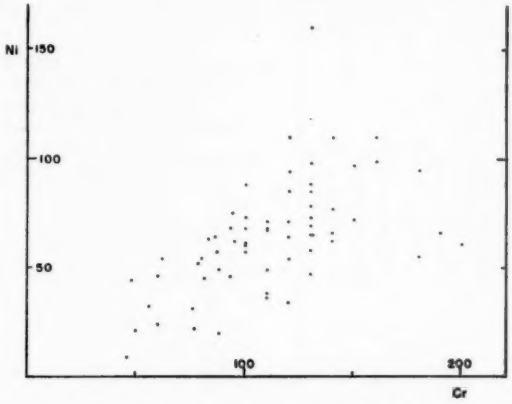

FIGURE 4.—CORRELATION OF NICKEL AND CHROMIUM IN LITTLETON FORMATION

Relations between Groups of Elements

It might be expected that certain elements would behave in a related manner, owing to their similarities. For instance, the tables of analyses in Part I (Shaw, 1954) suggest that rocks rich in chromium are also rich in nickel, and so on. To examine these relations correlation diagrams were prepared, in which the amounts of two elements were plotted against each other for each analysis. Good correlation is revealed by a tendency toward a linear distribution; poor correlation is shown by a "pudding" distribution.

The best correlation was found for nickel and chromium (Fig. 4). In addition the pairs nickel-cobalt and vanadium-chromium show fairly good positive linear correlation. Other pairs of elements give pudding diagrams, as for example in Figure 5, where there is no evidence of any related behavior between lithium and lead. This was unexpected, since in view of the lithium-lead metasomatism it was expected that rocks rich in lithium would also be rich in lead.

Since the four ferrides show some degree of correlation in pairs, diagrams were plotted to see if they correlate in threes—*e.g.*, to see if a rock rich in nickel and chromium is also rich in vanadium. Such diagrams should be three-dimensional, but the type of diagram shown in Figure 6 is suitable, where the sum of nickel and chromium is plotted against vanadium.

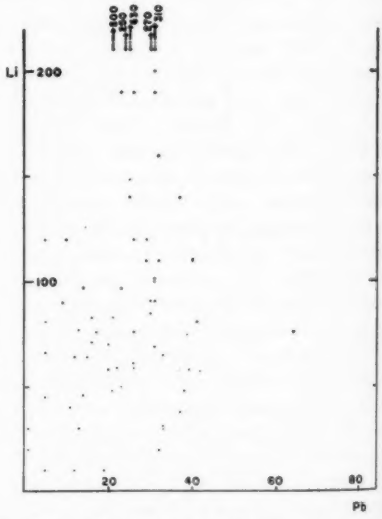

FIGURE 5.—CORRELATION OF LITHIUM AND LEAD IN LITTLETON FORMATION

Some degree of positive correlation does exist, but the correlation between vanadium plus chromium and cobalt is low, as is that with nickel plus chromium and cobalt.

On theoretical grounds a good linear correla-

tion is expected between nickel and cobalt, which have similar ionic potentials, and reasonably good correlation is expected among nickel, cobalt, chromium, and vanadium, since these elements tend to accumulate in argillaceous sediments[1]. In a few cases this was found to be so, for some impure quartzites excluded from the tables of analyses were low in all four elements. But the diagrams show that there is only an approach to the theoretical conditions and that random fluctuations are not negligible.

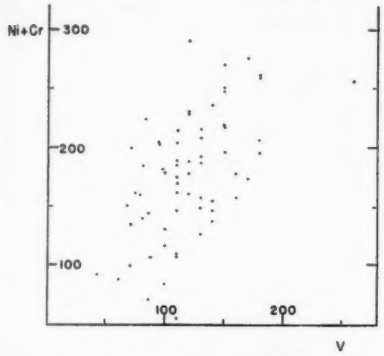

FIGURE 6.—CORRELATION OF NICKEL PLUS CHROMIUM WITH VANADIUM IN LITTLETON FORMATION

Many authors have quoted nickel-cobalt ratios for various rocks. The previous paragraphs indicate the difficulties of choosing any characteristic ratio for pelitic sediments, since a single ratio can be used only if there is perfect linear correlation. In the present case the calculated values range between 1.02 and 8.43 with most figures between 3 and 4. It therefore suits the present purpose to quote the ratio of the average nickel to the average cobalt content, which is 3.6. This figure is not significantly dif-

[1] Vanadium accumulates in hydrolysates as a sulfide rather than a hydroxide, according to some authors (Leutwein, 1951).

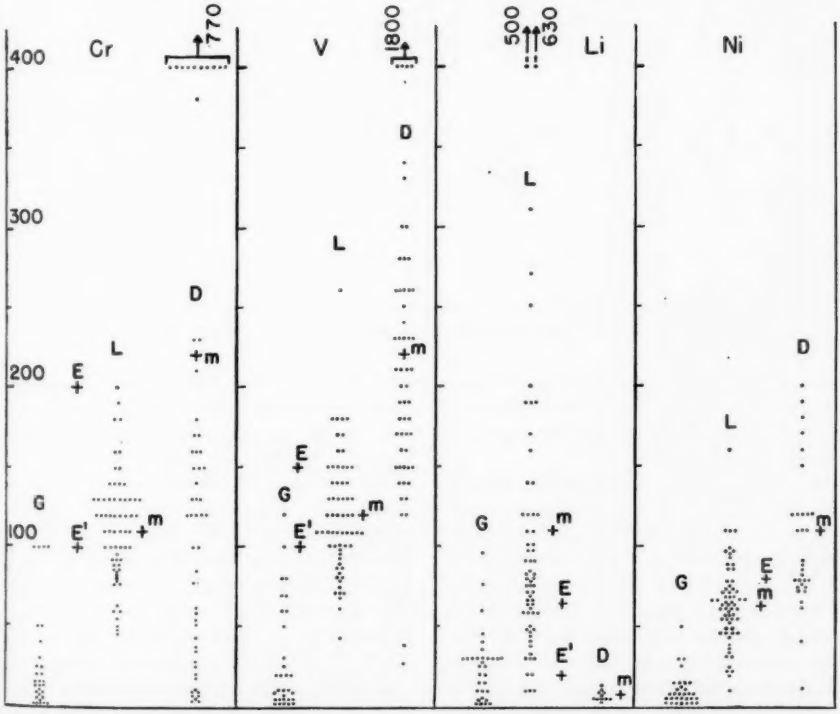

FIGURE 7.—CR, V, LI, AND NI IN GRANITES (G), SHALES (L), AND DIABASES (D)

ferent from the ratio of the crustal abundances, which is 3.5.

Comparison with Other Rock Types

By way of conclusion it is interesting to compare and contrast the trace-element content of argillaceous rocks with other rock types. There are relatively few reliable data. Averages are of no use for comparison unless the range of composition is also known.

The data chosen for comparison are: a suite of 59 Ontario diabases of several ages, investigated at the Massachusetts Institute of Technology (Fairbairn, Ahrens, and Gorfinkle, 1953) and here referred to as diabase (D); 8 granophyres from the Skaergaard intrusion, analyzed by Wager and Mitchell (1951, Table D, Nos. II–VI and VIII–X); 14 Caledonian aplites, granodiorites, and similar rocks, analyzed by Nockolds and Mitchell (1948; Table II, Nos. 15–21; Table III, Nos. 28, 30–33, 35–36); 9 granites and quartz syenites of the White Mountain magma series of New Hampshire, analyzed at McMaster University. The last three suites of rocks may be considered representative of the wide field of granites (G). In addition crustal-abundance data are used: the

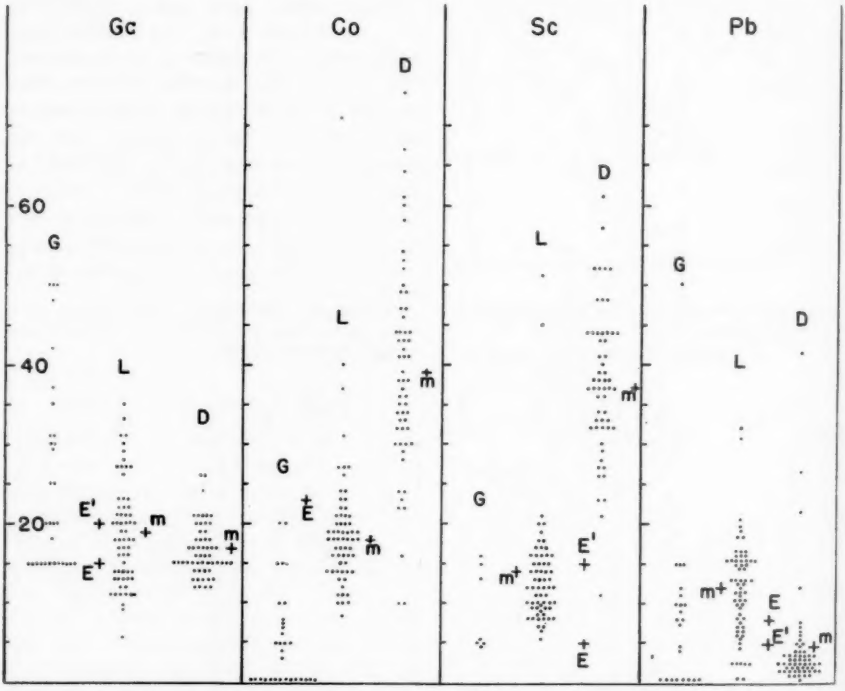

Figure 8.—Ga, Co, Sc, and Pb in Granites (G), Shales (L), and Diabases (D)

symbol (E) refers to figures taken from Rankama and Sahama (1950, Table 2,3).

To present the data clearly Figures 7, 8, and 9 have been prepared. Each point on the diagrams represents an analysis, and the range in composition for each rock type is evident. The symbol *m* refers to the mean value for the group near by. An overall view shows that only in a few cases is the range of variation of a given rock type restricted and exclusive. The general tendency is for the ranges to overlap extensively, so that it would not be possible to distinguish a granite from a clay, for example, by the strontium content. Moreover the granites appear much less homogeneous than

the diabases and pelites; this is undoubtedly real, since the groups chosen were of widely different origins and characteristics. Moreover there is wide variation in each granitic suite considered alone, although this is not apparent from the diagrams.

composition but are clearly differentiated from the granites. Cobalt behaves like these elements but shows less difference between granite and shale.

Lithium is similar to the last insofar as the granites and shales are concerned, but differs in

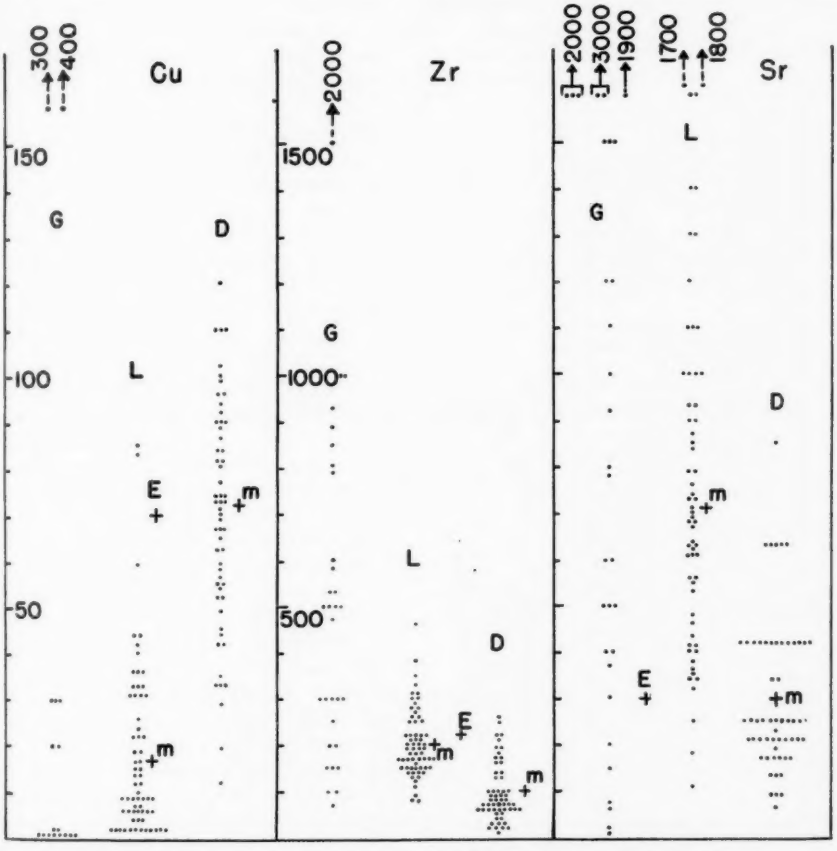

FIGURE 9.—Cu, Zr, and Sr in Granites (G), Shales (L), and Diabases (D)

Gallium shows few features of interest, but the data suggest that a crustal abundance of about 20 ppm would be more suitable than 15.

Chromium is one of the few elements that shows distinct differences between the rock types; vanadium and nickel do also. With all three elements the granites are all of similar composition, whereas the diabases are unusually variable. Shales are of an intermediate

the low values for diabases, which is to be expected on crystal chemical grounds. Unfortunately the lithium content was not quoted for most of the diabases, but the tendency seems to be for strong homogeneity. Shales tend to be richer in lithium than both granite and diabase, implying that the extra lithium cannot be derived from the erosion of igneous rock.

Copper is usually low in the granites, except

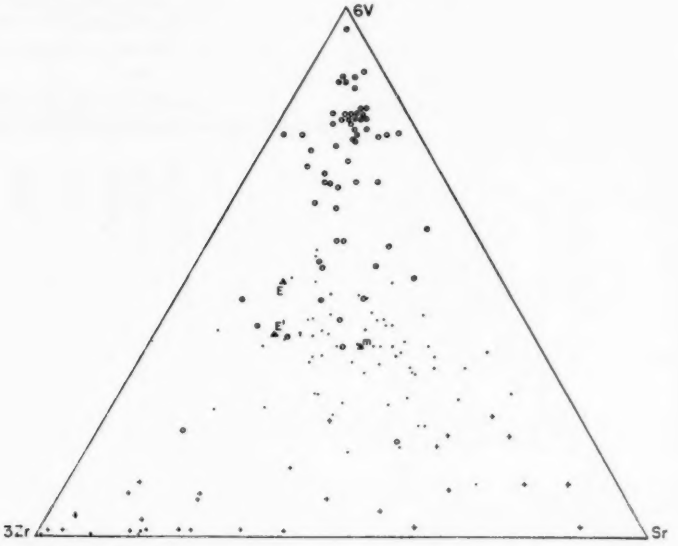

FIGURE 10.—V-ZR-SR RELATIONS IN GRANITES (crosses), SHALES (dots), AND DIABASES (circles)

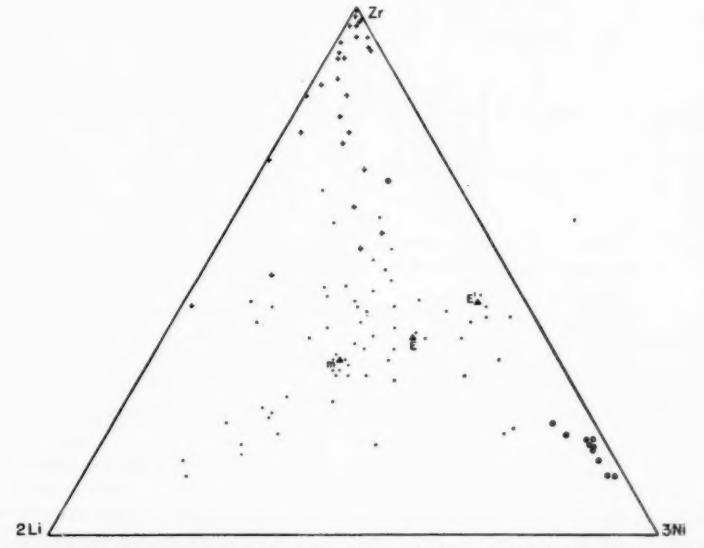

FIGURE 11.—ZR-LI-NI RELATIONS IN GRANITES (crosses), SHALES (dots), AND DIABASES (circles)

for two of the early Skaergaard granophyres, which probably contain sulfide minerals. The shales are clearly impoverished in copper with respect to the diabases.

Scandium behaves in a similar way to copper, but the values are less widely spread with each rock type. The distribution of zirconium is rather different; diabase contains the least,

and the shales are intermediate. The zirconium content of granitic rocks is clearly variable.

Strontium shows the least homogeneity of all the elements; the values extend from 5 to 3000 ppm for granites and show a similar long range in shales. However, a logarithmic scale would reduce the range to a magnitude more commensurate with the other elements.

For lead there is little to say, except to comment on the strongly homogeneous diabase group.

Although it is not the primary purpose of the present paper to discuss crustal-abundance figures, Figures 7, 8, and 9 indicate that the quoted figures (E) are in error for some elements, bearing in mind that the "average igneous rock" is taken as being representative of the crust. It is suggested that the following revised estimates be adopted (E^1) as being at least closer to the average igneous rock (the previous figure is given in parentheses): Ga, 20 (15); Cr, 100 (200); V, 100 (150); Li, 20 (65); Sc, 15 (5); Pb, 10 (16).

To emphasize some of the differences in composition of these three common rock types, ternary diagrams have been prepared for the groups V-Zr-Sr and Zr-Li-Ni (Figs. 10, 11). For clarity, some elements have been multiplied by a constant, and the actual quantities plotted are 6V, 3Zr, and Sr; Zr, 2Li, and 3Ni (all reduced to percentages). The combinations of elements chosen give the most distinct separation of the various composition fields, irrespective of petrogenetic significance. Figure 10 shows that the fields of composition of granite, diabase, and shale are reasonably well separated but overlap at the edges. The diabases are (relatively) rich in vanadium, owing to its tendency to accumulate in early crystallized mafic silicates and oxides. By contrast the granites, with relatively low proportions of ferromagnesian minerals, are depleted in this element. The opposite behavior of zirconium and strontium is evident, whereas pelitic sediments are in an intermediate position. The equation 6V = 3Zr = Sr is approximately true (in a statistical sense) for these rocks.

At first sight Figure 11 appears to show more clearly distinct composition fields, but few diabases are plotted. As in Figure 10 the concentration of zirconium in granite and depletion in diabase contrasts effectively with the reverse situation for nickel. The latter element, like vanadium, accumulates in early ferromagnesian minerals. Only in the shales and schists is there any tendency toward a relative abundance of lithium, and the rocks displaced toward the lithium corner are all schists and gneisses which have undergone an addition of this element.

In both diagrams the effect of revising the crustal abundances is clearly seen.

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HAMILTON COLLEGE, MCMASTER UNIVERSITY, HAMILTON, ONTARIO
MANUSCRIPT RECEIVED BY THE SECRETARY OF THE SOCIETY SEPTEMBER 16, 1953
PROJECT GRANT 566/51/52

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 65, PP. 1183–1198, 5 FIGS. DECEMBER 1954

STRATIGRAPHIC DISTRIBUTION OF LIPOID SUBSTANCES IN CEDAR CREEK BOG, MINNESOTA

BY F. M. SWAIN AND N. PROKOPOVICH

ABSTRACT

The lake and bog deposits of Cedar Creek Forest, Isanti and Anoka counties, Minnesota, consist of a multiple-facies accumulation of marl, peat, copropel, and sapropel. Chromatographic analyses of the lipoid extracts of samples of the sediments show measurable amounts of saturated and aromatic hydrocarbons as well as large proportions of asphalts and polar lipoid compounds. In general composition the "oily" fractions somewhat resemble a Venezuelan asphalt. The ratio of total lipoids in the peat, marl, and underlying sand, respectively, in this deposit is approximately 12:3:1. The highest measured content of saturated hydrocarbons occurs just above the marl. The other fractions show no noteworthy relationship to depth or type of material. Most of the variation in distribution of the lipoids appears primary, but some shifting of the hydrocarbons may have resulted from movements of ground water within the bog. The data suggest that the hydrocarbon formation or liberation from the source material took place concomitantly with the accumulation of the lake and bog deposits.

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Introduction

A study of the stratigraphy of bituminous deposits has led to an examination of the lipoid[1] content of some post-glacial lake and bog deposits in Minnesota. An investigation of the bog and lake sediments of Cedar Creek Forest, Anoka and Isanti counties, Minnesota, was undertaken because of the limnological and ecological studies in this area by several scientists, including the outstanding efforts of Lindeman (1941a; 1941b; 1942a; 1942b).

The distribution of lipoids at several localities in Cedar Creek Bog is discussed in this paper. A further description of the sediments of this and other lake and bog materials is in preparation.

The Cedar Creek Forest area (Fig. 1) is a late-senescent stage bog that originated as a late Wisconsin lake which may be an ice-block depression on the Anoka sand plain (Lindeman, 1941a, p. 101). The early deposits of the basin (Fig. 2) consist of sideritic marl, perhaps early-eutrophic,[2] at a depth of about 35 feet below the present level of the shallow lake. The succeeding deposits up to 11–12 feet below the lake consist of marl containing organic matter of coprogenic nature (copropel)[3] with a thin traceable layer of dark-brown copropel in the middle. Overlying the marl is a layer of eutrophic finely divided brown copropel and black sapropel 6–8 feet thick near the lake but thinner toward the bog margins. This is in turn overlain by sedge-peat and then by coarser forest peat and *Sphagnum* peat up to the present bog surface. A portion of the bog near the lake is quaking (Fig. 2). The water table fluctuates seasonally several feet (Buell, 1941, p. 317).

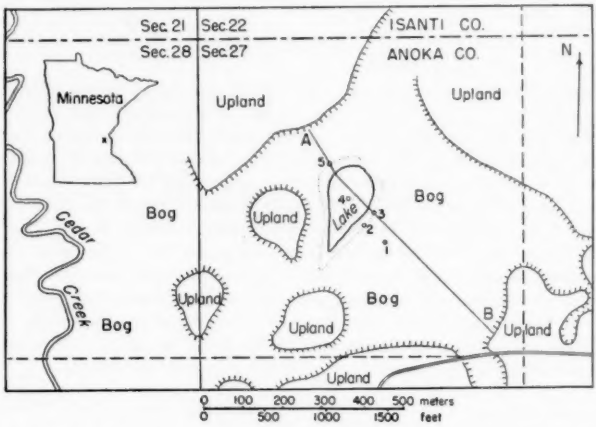


Figure 1.—Sketch Map of Part of Cedar Creek Forest from Aerial Photograph
Showing locations of stations sampled. A–B, line of stratigraphic section given in Figure 2. Location of the area is given in the small inset.

Flint and Deevey (1951, p. 272) using data assembled by Lindeman show that the bog is post-Mankato and represents the later part of pollen zone A (spruce-fir) and all subsequent zones up to the present. The dark-brown copropel layer referred to above occurs in the copropel-marl subfacies at depths ranging from 20 to 30 feet or more (Fig. 2). The layer represents pollen zone B (pine) and has a radiocar-

[1] "Lipoid" materials include all the substances extractable with various petroleum solvents, in contrast to "lipid" material which refers to saponifiable oxygenated fats, exclusive of hydrocarbon and certain other nonsaponifiable ether-soluble compounds.

[2] eutrophic, nutritious, referring to lakes containing abundant nutritive salts, as contrasted to oligotrophic lakes which are poor in nutrients.

[3] copropel (*kopros*, dung + *pēlos*, mud) dark-brown or gray coprogenic ooze, containing chitinous exoskeletons of benthonic arthropods in addition to reworked organic matter. The term is here suggested to replace gyttja which has had somewhat vague application. Sapropel is black, fine to coarse-textured detritus formed by anaerobic bacterial decomposition of organic detritus in lakes and seas.

bon age of 7988 ± 420 years (Flint and Deevey, 1951, p. 272).

Acknowledgments

Appreciation for their assistance and encouragement is expressed to Professors G. A. Thiel, J. W. Gruner, H. E. Wright of the Department of Geology; D. B. Lawrence, Department of Botany; S. F. Eddy, Department of Zoology; E. B. Sandell and C. F. Koelsch, School of Chemistry; and H. H. Wade, Acting Director, Mines Experiment Station, University of Minnesota. Mr. P. V. Smith, Jr., Standard Oil Development Company, kindly provided information about the chromatographic method of analysis. Paul L. Engel and K. E. Dickinson aided in field and laboratory work.

The study has been supported by grant-in-aid 391-3201-6100 of the Graduate School, University of Minnesota.

Permission to study the Cedar Creek Bog samples has been granted by the Committee in charge of Cedar Creek Forest, A. N. Wilcox, Chairman.

Procedures

Samples of the bog sediments were obtained in August 1953 and in January 1954 with a Davis peat-borer and were stored in 300 ml test tubes.

Electrometric determinations of pH and Eh (Table 1) with a Beckman meter were made on the summer collections about 3 hours after collecting; the winter collections froze and determinations were made after bringing them to room temperature 2 days later. Part of each sample was set aside for further study of the organic debris and inorganic sediments. Portions of 6 samples were taken for C and N content (Table 1).

Fourteen core samples from station 1, ranging in depth from 1 to 15 feet, two deep samples from station 2 and a sample from the lake bottom at station 4 were selected for hydrocarbon analysis. A known portion of each sample was extracted twice with a mixture of benzene (75%), acetone (15%), and methanol (15%) as suggested by Smith (1952, p. 437). Blank runs on the solvent left a residue of less than .01 per cent by weight; this was considered satisfactory.

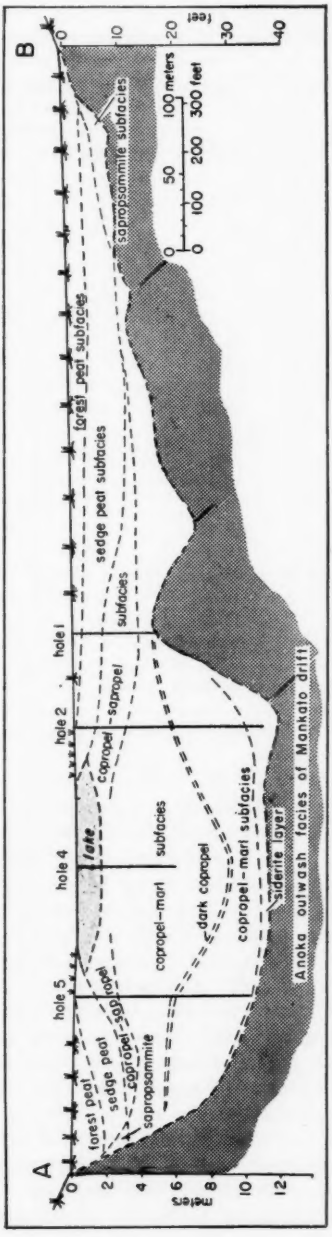


FIGURE 2.—Northwest-southeast Cross Section Through Part of Cedar Creek Forest

Showing subfacies of the peat and marl accumulation. Modified after Lindeman (1941a). Locations and depths of stations sampled in this study are shown except station 3 which is directly back (NE) of station 2.

Each wet sample of sediment was Soxhlet-extracted at refluxing temperatures for 8 hours. These extracts were separated from the contained sample water in a separatory funnel of water-pumped nitrogen in a desiccator connected to a filter pump. The resulting residues, representing the lipoid content, ranged from 0.5 per cent of the total sample in the sand to

TABLE 1.—MEASUREMENTS OF pH, Eh, CARBON, NITROGEN, AND CARBON/NITROGEN RATIOS IN SAMPLES FROM CEDAR CREEK BOG

Station	Depth (ft)	pH	Eh (mv)*	% C†	% N†	C/N
1	3–4	7.1	+325	—‡	—	—
1	4–5	—	—	47.23	2.31	20.4
1	6–7	7.3	+405	—	—	—
1	7–8	—	—	47.59	2.77	17.2
1	9–10	7.4	+365	48.01	3.36	14.3
1	11–12	7.7	+415	9.78	0.9	10.8
1	12–13	7.25	+415	—	—	—
1	13–14	—	—	15.13	0.75	20.2
1	14–15	—	+445	—	—	—
2	35–36	7.15	+125	8.47	0.9	9.4
3	26.5–27.5	7.5	+167	—	—	—
4	14–15	7.5	+281	—	—	—
4	15–16	7.1	+185	—	—	—
4	16–17	7.1	+215	—	—	—
4	17–18	7.5	+224	—	—	—
4	19–20	7.8	+275	—	—	—
4	20–21	7.45	+256	—	—	—
4	21–22	7.4	+257	—	—	—
4	22–23	7.6	+299	—	—	—
	Lake water	7.5	+475	—	—	—

* Corrected for potential of calomel reference electrode, the E_o of which is taken as +245 mv at room temperature

† School of Chemistry, University of Minnesota, J. L. Swenson and O. Runquist, microanalysts

‡ Not determined

involving several stages of separation and dilution with fresh solvent. The samples were then dried at 105°C and extracted with fresh solvent for a second 8-hour period. The distillate was clear long before the end of the extraction period. Some additional lipoids may have become available as a result of the drying; Waksman (1936, p. 159) quoting Schneider and Schellenberg states that the ether-soluble fractions of peat and coal increase with a rise in temperature during extraction under pressure. Neither the wet nor dry sample extracts showed fluorescence. Hydrocarbon analyses were run separately on the wet and dry extracts of two samples; no appreciable differences in results were found, so the extracts were combined.

After reduction by distillation, evaporation of the solvent was accomplished with a stream

9.7 per cent in the middle part of the peat (Table 2).

Each lipoid residue was then separated by chromatography involving elution of successive fractions from a column of activated alumina (Harshaw, Al-0109-P) using the procedure described by Smith (1952, p. 437–39). Normal heptane, benzene, pyridine, and acetone were the successive eluting agents.

The following ratio of alumina and solvents was used:

8 g alumina
5 ml N-heptane prewet
12 ml each of N-heptane and benzene
9 ml pyridine
6 ml acetone

The amount of the heptane cut, dried to constant weight under nitrogen, was taken as the

TABLE 2.—DESCRIPTIONS OF SAMPLES

Station	Depth (ft.)	Description of dried sample	Dry wt. of sample (gm)	Moisture %	Wt. of lipoids (gm)	Lipoids % of sample
1	1–2	Med. gray-brown, med. and coarse-textured peat; a few carbonized fragments; cell structure well preserved	2.0030	88	.1460	7.3
1	2–3	Med.-dark gray-brown sapropel-copropel-peat and peat-copropel, finely textured; *Daphnia* exoskeletons; insect parts; more hygroscopic than 1–2 ft.	1.9495	89	.1073	5.5
1	3–4	Med.-dark gray-brown, slightly sandy copropel-peat; coarser than 2–3 ft.; fine fraction dark brown, resinous, with coprogenic pellets; few ostracodes and exoskeletons of other benthos	1.3610	91	.0694	5.1
1	4–5	Med. gray-brown, very fibrous copropel-peat, finer-textured than 3–4 ft.; many insect parts, *Cyclops*, *Daphnia*; abundant pollen; slightly sandy	0.9830	94	.0783	7.9
1	5–6	Med. gray-brown, coarsely fibrous copropel-peat; matrix of dark-brown, resinous, coprogenic pellets and irregular aggregates; few *Daphnia* and other chitinous exoskeletons	1.5008	90	.0921	6.1
1	6–7	Dark gray-brown, finely fibrous sapropel-copropel-peat, some chitinous exoskeletons, few ostracodes	1.1933	93	.0741	6.2
1	7–8	Dark gray-brown, finely fibrous, tenaceous sapropel-peat-copropel; very finely divided copropel forms most of matrix; peaty portion mostly pondweeds; few seeds; very few arthropod exoskeletons	1.4550	93	.0874	6.0
1	8–9	Dark gray-brown peat-copropel-sapropel; finely divided black and brown resinous organic matter and finely divided peat; insect parts; carbonized fragments; sand grains	1.6610	87	.1612	9.7
1	9–10	Same as 8–9 ft.	2.2170	89	.1586	7.1
1	10–11	Dark gray-brown to black copropel-peat-sapropel, with most of the coarser particles partly decayed dark brown, resinous; pondweed fibers; *Daphnia* and other exoskeletons; seeds; pollen; scattered fine-coarse quartz grains	1.9080	90	.0819	4.3
1	11–12	Very light-gray, microgranular, soft, porous, partly sandy marl; white, altered mollusk fragments; seed pods, *Daphnia* exoskeletons	4.4100	68	.0679	1.5
1	12–13	Very light-gray, soft, porous, very sandy marl; seed pods	7.3530	56	.0951	1.3

TABLE 2.—*Continued*

Station	Depth (ft.)	Description of dried sample	Dry wt. of sample (gm)	Moisture %	Wt. of lipoids (gm)	Lipoids % of sample
1	13–14	Light-gray to pale buff, sandy, copropel-marl; soft, porous; sand, finely granular marl, and copropel intimately intermixed; exoskeletons of *Daphnia*, etc.; seed pods	4.9610	70	.1065	2.1
1	14–15	Light-gray, subangular to well-rounded fine- to medium-grained, slightly carbonaceous and bituminous sand; few rock fragments	7.5910	61	.0355	0.47
2	12–13	Light gray-brown, microcrystalline, platy, and granular-textured ostracodal copropel-algal marl; copropel is medium to light brown and is mixed with finely granular marl; platy marl fragments evidently represent deposition around leaf stalks of *Potamogeton* or other pondweed; they show impression of cell structure on one side and a porous fabric on the other; ostracodes include *Candona* cf. *caudata*, *Darwinula stevensoni*, *Cypridopsis vidua*, and *Cypria lacustris*	3.6704	79	—	—
2	25–26	Light dove-gray, soft, porous, microgranular copropel-marl, with abundant poorly preserved fragile ostracodes and *Daphnia*; many rust-brown spots probably due to oxidation of siderite when sample was dried (*See* analysis, Table 4.)	5.6403	—	.0722	1.2
2	35–36	Light rust-brown, microgranular, very sideritic marl (*see* Table 4); fresh samples dark gray to black; few ostracodes, including *Candona* sp., *Cyclocypris* sp.	5.2058	71	.0847	1.6

paraffin-napthene fraction, the benzene cut as the aromatic fraction, and the pyridine-plus-acetone cut as the asphaltene fraction. The benzene and especially the pyridine cuts were difficult to bring to constant weight. The results are given in Table 3. The combined hydrocarbons averaged 0.68 per cent of the total sample (dry weight) in the peat, 0.17 per cent in the marl, and was 0.14 per cent in the basal sandy subground of the bog. The terms paraffin, naphthene, and aromatic are used for convenience; pure compounds of members of these series have not been determined by chemical analysis because of the small size of the samples obtained. It is hoped that eventually enough peat can be extracted to provide a residue suitable for regular chemical analysis. Smith (1954, p. 384), working with larger samples, demonstrated the presence of several hydrocarbon series in chromatographic separations of extracts from Recent marine sediments.

The reproducibility of the analyses varied from 0.2–11 per cent in the nine fractions, of which duplicates were studied. The 3 principal sources of error are: (1) the volatility of the lipoid extracts make it difficult to maintain constant weight, (2) it is difficult to dissolve each fraction completely and transfer it to the

column without slight losses, and (3) some of the fractions may be unstable at room temperature. Smith (1954, p. 387) found no evidence of changes in the hydrocarbon compounds, such as formation of aromatics from olefine compounds during the chromatographic separation. Despite the small residues left after blank runs with solvents, a possible source of error lies in the formation of lipoids from the acetone.

Two of the heavy pyridine cuts were eluted from fresh columns with pyridine and acetone. No residue remained on the alumina, indicating that the previous separation had been complete.

TABLE 3.—CHROMATOGRAPHIC ANALYSES OF LIPOID EXTRACTS

Depth	Predominant Material	Paraff-Naphth		Aromatic		Asphaltic	Remaining on Alumina % Lip.	Combined HC % of Sample
		%HC	%Lip	%HC	%Lip	% Lipoids		
Sta. 1								
1–2	peat	44.5	5.9	55.5	7.5	28.4	58.2	0.98
2–3	copropel	27.5	1.1	72.5	3.0	28.4	67.5	0.22
3–4	peat	34.0	5.6	66.0	10.9	35.2	48.3	0.85
4–5	peat	47.0	7.7	53.0	8.5	30.8	53.0	1.27
5–6	peat	92.0	2.5	8.0	0.2	24.3	73.0	0.17
6–7	peat	60.0	8.4	40.0	5.5	27.0	59.1	0.87
7–8	copropel	40.5	3.2	59.5	4.7	26.7	65.4	0.48
8–9	sapropel	0	—	100.0	4.8	11.7	83.5	0.48
9–10	sapropel	40.0	0.9	60.0	1.3	14.5	83.3	0.16
10–11	sapropel	93.0	29.8	7.0	2.2	28.0	40.0	1.38
11–12	marl	40.5	4.2	59.5	6.1	34.5	55.2	0.16
12–13	sandy marl	24.5	3.4	74.5	10.2	23.4	63.0	0.18
13–14	marl	66.0	5.1	34.0	2.6	29.3	63.0	0.17
14–15	sand	29.0	8.3	71.0	19.7	44.3	27.7	0.14
Sta. 2								
25–26	marl	65.0	8.6	35.0	4.6	26.0	60.8	0.17
35–36	sideritic marl	30.0	5.5	70.0	10.9	21.9	6.17	0.29
Sta. 4								
12–13	copropel	32.4	2.5	67.5	5.2	30.8	61.4	0.12

RESULTS

Paraffin-Naphthene Fraction

This fraction formed up to 93 per cent by weight and averaged 46 per cent of the hydrocarbon portion of the samples, and up to 30 per cent of the lipoid extract. In all samples the residue consisted of colorless, slightly odorous light oil, exhibiting pale-blue fluorescence. Several samples contained colorless bladed or hairlike crystals, showing high-order birefringence and parallel extinction.

Aromatic Fraction

This cut formed up to 100 per cent averaging 54 per cent of the hydrocarbon portion of the sample and up to 20 per cent of the lipoid fraction. Most of the aromatic residues were odorous pale-yellow heavy oil or wax with tiny disseminated colorless granular or needlelike crystals. The aromatic fraction at 3–4 feet (station 1) had long hairlike crystals like those in some of the paraffin fractions and was the darkest. The 5–6 foot fraction was colorless oil. Most of the aromatic fractions showed pale yellow-green to gold weak to bright fluorescence, but the 2–3 foot and the 6–7 foot residues had blue fluorescence. The 14–15 foot residue

was especially difficult to bring to constant weight and continued to give off a strong odor showing presence of volatile components and pointing to the unreliability of the tabulated percentages at this level. In the 35–36 foot sample during elution, a narrow red band formed at the heptane-benzene front and moved down with the benzene, which then became yellow-orange. In the other elutions the heptane-benzene front was followed by blue fluorescence of the benzene. The fluorescence of the benzene is caused by some impurity (Prof. R. Livingston, Dept. of Chemistry, Univ. of Minnesota), but this was not detected in the blank runs on the solvent.

TABLE 4.—PARTIAL INORGANIC ANALYSES OF SOME OF THE CEDAR CREEK BOG SAMPLES*

Station	Depth (feet)	$CaCO_3$	$MgCO_3$	SO_4	Total S†	Total Fe‡	Total P§
1	4–5	7.99	0.96	nil	0.21	2.27	—
1	7–8	6.88	0.90	nil	0.32	1.59	—
1	9–10	7.11	0.88	nil	0.80	1.72	—
1	11–12	74.80	2.37	nil	0.37	1.04	0.021
1	13–14	40.75	2.05	nil	1.46	2.01	0.036
2	35–36	38.60	1.13	nil	0.43	15.63	0.255

* Analyses by Mines Experiment Station, University of Minnesota, Vernon Bye, Analyst

† May be present as sulfide, native sulfur, or as an organic compound

‡ May occur as siderite, ankerite, marcasite, ferrous sulfide hydrate, or in some other form

§ May occur as inorganic apatite, vivianite ($Fe_3P_2O_8 \cdot 8H_2O$), bobierrite ($Mg_3P_2O_8 \cdot 8H_2O$), or as organic phosphate ("collophane").

Asphaltene Fraction

The pyridine and acetone cuts constitute the asphaltic portion of the extracts plus an undetermined amount of nonpolar organic compounds containing oxygen, nitrogen, and possibly sulfur. This fraction far exceeded the other two in most of the samples, averaging 27 per cent and attaining 44 per cent of the total lipoids in the 14–15 foot sample at station 1. The asphalts consisted of light to dark yellow-brown and greenish-brown heavy oil and wax with a tarry odor. The fractions at 2–3 feet, 6–7 feet, 10–11 feet, station 1, and 35–36 feet, station 2, were very viscous and sticky. The 6–7 and 7–8 foot fractions were reddish brown. The asphaltene fractions fluoresced not at all or rarely weak golden to orange. The fractions were characteristically clear; a few asphalt fractions contained particulate material.

Inorganic Constituents

Partial chemical analyses were made of a small residual part of several samples (Table 4) to determine any possible relationship between the inorganic constituents and the occurrence of the hydrocarbons.

DISCUSSION

General Statement

The stratigrapher should find value in the information obtainable from similar chromatographic analyses of extracts from bituminous sedimentary rocks. For example, Nevin (1945, p. 285) pointed out that in Upper Devonian (Genesee) black shale of New York State a facies change from carbonaceous on the east to bituminous on the west could be recognized by the amount of oil obtainable by distillation from the shales. Because of the small amount of equipment and the relative ease and rapidity of making the analyses, chromatographic analysis is much more adaptable to stratigraphic studies than are processes of fractional distillation that have been applied to study of crude oils (Newmann *et al*, 1941; Barr, *et al*, 1943; Tulsa Geol. Soc. Res. Comm., 1947).

In the present study, many bottom samples from lakes in Minnesota, and bituminous rock samples of several ages are being analyzed to learn more about the possible stratigraphic value of the lipoid substances.

Total Extractable Fraction

The materials extractable from peat with petroleum solvents and alcohol, include, in addition to hydrocarbons and "asphaltene", resins, nitrogenous fats, tannin, bitter substances, alkaloids, chlorophyll, and some carbohydrates (Waksman, 1936, p. 278). In chromatographic separation a large part of these substances other than hydrocarbons and as-

phaltene remain adsorbed on the alumina and color it green or brown.

In the deposit studied, the only clear-cut relationship between the kind of bog material and the total extractable fraction is that the extractable fraction decreases from the base of the peat downward into the marl. The relatively high lipoid fraction in the 8–9 and 9–10 foot samples (Table 2) is partly the result of the increase of nitrogenous compounds (Table 1) because of microbial decomposition of carbohydrates during the formation of the peat (Waksman 1936, p. 277). The high lipoid content just above the marl is probably due also in part to the relatively higher fat content of the original plankton-rich source material. Considerable microbial activity occurs on the margin of bog lakes, where sedge growth is dense. This causes patches of sapropel to form in the shallow near-shore waters as well as in the hypolimnion zone of off-shore parts of the lake. In the Cedar Creek basin, such material should form along the peat-marl front as the peaty portion advanced upon the marl toward the middle of the bog (Fig. 2).

Waksman states (1936, p. 278) that "lowmoor" peats, such as those studied here, contain less ether- and alcohol-extractable substances than "highmoor" (*Sphagnum*-rich) peats, which are reported to have 20 per cent or more "bitumen". Pollen-rich peats contain the most extractables. An increase in age in *Sphagnum* peat is marked by an increase in extractables; in lowmoor peats this is not always so, both because of an original deficiency of cellulose in the form of woody tissue and because of a lower decomposition rate in the more stable, lignin-rich lowmoor peats. In the present samples little or no *Sphagnum* peat was found. These plants are present mainly in the upper few inches of the bog. In the 4–5 foot sample the slight increase in lipoids may be related to the abundant pollen noted at that horizon.

Saturated Hydrocarbons

The hydrocarbon portions of "peat wax" have not been studied in detail, although solid paraffins, such as triacontane ($C_{30}H_{62}$) and pentatricontane ($C_{35}H_{72}$), forming 15–20 per cent of the wax have been reported (Titow, 1932, p. 266). A solid hydrocarbon, hentriacontane ($C_{31}H_{64}$), was extracted from peat with boiling alcohol (Schreiner and Shorey, 1911, p. 83).

In the present samples, the quantity of saturated hydrocarbons of the paraffin and naphthene series varies. It has not yet been determined whether this variability is traceably consistent within the bog, and whether it is related to original variation in source material, state of decomposition, or other factors. There is no direct increase of the hydrocarbon fractions with increased depth such as has been reported for total lipoids in a Maine peat bog (Waksman, 1936, p. 269). The high content of saturated hydrocarbons at 10–11 feet, amounting to more than 1 per cent of the total sample, probably represents an original accumulation rather than a concentration of the hydrocarbons from higher levels.

The sources of the saturated hydrocarbon residues are probably fats or lipids of the plant and animal cytoplasm, and decomposed cellulose. Bacterial decomposition of cellulose, if carried to final stages, produces varying amounts of methane gas in two principal steps (Ruttner, 1953, p. 171):

(1) hydration of cellulose and formation of hexose (glucose):

$$C_6H_{10}O_5 + H_2O = C_6H_{12}O_6;$$

(2) a series of reactions ending with methane formation under anaerobic conditions, but in an alkaline environment:

$$C_6H_{12}O_6 = 3CO_2 + 3CH_4.$$

Methane is formed by specialized bacteria of which *Methanosarcina* is one of the most important (Liebmann, 1950, p. 14). These bacteria occur in an entirely anaerobic layer in copropel where, unable to utilize fresh cellulose, they form methane from decomposed products of low molecular weight, as fatty acids, alcohols, and ketones. The concentration of saturated hydrocarbons at 10–11 feet (Table 3) may have resulted partly from such a reduction of carbohydrates along the advancing peat-marl front.

Other gaseous hydrocarbons, including ethane, propane, ethylene and propylene, have

recently been detected in glucose fermentation (Davis and Squires, 1954, p. 381).

It is uncertain whether cellulose itself was an important source. Waksman (1936, p. 279) cites data to show that in lowmoor peats cellulose and hemicellulose are both relatively less important than the more resistant lignin.

Measurable amounts of saturated hydrocarbons occur at shallow depths in the bog, showing that their liberation from cytoplasm or formation by decomposition of carbohydrates is accomplished simultaneously with the accumulation of the bog debris. This rate of accumulation based on the C^{14} date of 8000 years at a depth of about 25 feet would be approximately 320 years per foot; this average is subject to many modifications owing to change of climate, variations in plant populations, etc.

The crystals observed in some of the saturated fractions were not identified specifically, but their habit is like that in normal paraffin from $C_{24}H_{50}$ to $C_{44}H_{90}$ (Sachanen, 1945, p. 307). Kolvoort (1938, p. 338) observed a change in crystal system within normal $C_{24}H_{50}$ with increasing temperature up to the melting point at approximately 50°C: below 41°C crystals of this hydrocarbon are twinned plates and probably monoclinic (γ-form); at 41° the system is transitional to a twinned orthorhombic form (β-form), and at 46° it is transitional to probably hexagonal needles (α-form); at the transition points, the two types may exist in equilibrium. Both needles and plates were observed in the residues, but no further study of them was made. Sachanen (1945) reports an extensive literature on the petroleum wax crystals.

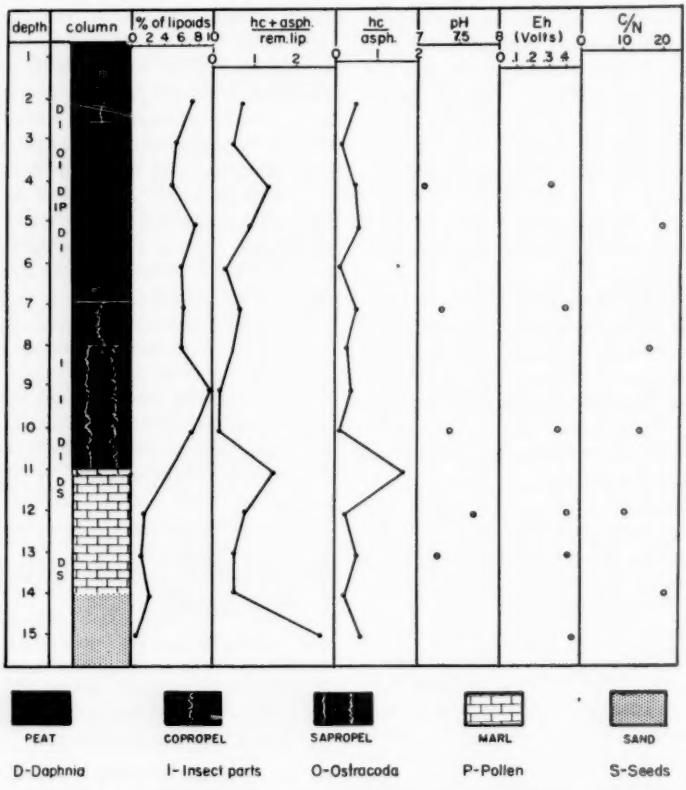
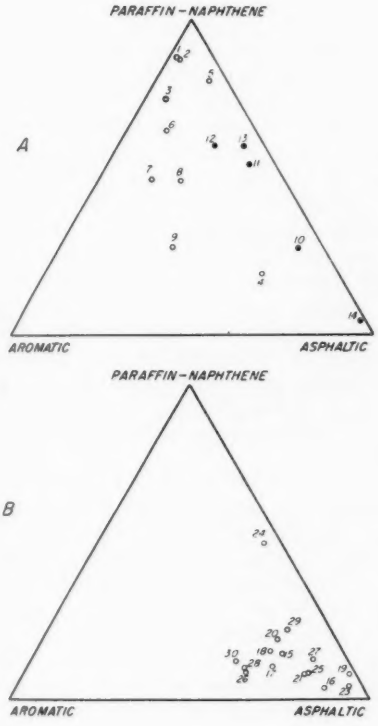


FIGURE 3.—COMPARISON OF SEDIMENTARY TYPES TO TOTAL LIPOIDS, HYDROCARBON FRACTIONS, AND OTHER PROPERTIES AT STATION 1, CEDAR CREEK BOG

Aromatic Hydrocarbons

The data show that aromatic hydrocarbons are present in significant amounts close to the bog surface. Lignins contain aromatic nuclei



A. Composition of crude oils (circles) (data from Sachanen, 1945) and recent samples from Gulf of Mexico sediments (discs) (data from Smith, 1952).
(1) Paraffin crude oil (paraffins 40%, naphthenes 48%, aromatics 10%, resins and asphalts 2%).
(2) Naphthene crude oil; Emba-Dossor crude (paraffins 12%, naphthenes 75%, aromatics 10%, resins and asphalts 3%).
(3) Naphthene crude oil; Baker crude (paraffins 9%, naphthenes 66%, aromatics 19%, resins and asphaltics 6%).
(4) Natural asphalt; Bermudez (paraffins 5%, naphthenes 15%, aromatics 20%, resins and asphalts 60%).
(5) Paraffin-naphthene crude oil; Oklahoma City crude (paraffins 36%, naphthenes 45%, aromatics 14%, resins and asphaltenes 5%).
(6) Naphthenic-aromatic crude oil; Santa Fe Springs, California crude (paraffins 20%, naphthenes 45%, aromatics 23%, resins and asphaltenes 12%).
(7) Naphthenic-aromatic crude oil; Borneo crude (paraffins 15%, naphthenes 35%, aromatics 35%, resins and asphaltenes 15%).
(8) Mixed asphaltic crude oil; Inglewood, California crude (paraffins 8%, naphthenes 42%, aromatics 27%, resins and asphaltenes 23%).
(9) Mixed asphaltic crude oil; Perm, Russia crude (paraffins 13%, naphthenes 15%, aromatics 40%, resins and asphaltenes 32%).
(10) Recent, Gulf of Mexico 3–4 feet (paraffin-naphthene 28%, aromatics 7%, asphaltic 65%).
(11) Do, 18–22 feet (paraffin-naphthene 55%, aromatics 7.7%, asphaltic 37.3%).
(12) Do, 102–103 feet (paraffin-naphthene 60.7%, aromatics 13.8%, asphaltic 25.7%).
(13) Recent, Laguna Madre, Texas (reducing environment) (paraffin-naphthene 60%, aromatic 6.6%, asphaltic 33.4%).
(14) Do (oxidizing environment) (paraffin-naphthene 4%, aromatic 1%, asphaltic 95%).

B. Composition of nonpolar lipoids; samples from Stations 1 and 2, Cedar Creek Bog. (Depths in feet)—15, 1–2; 16, 2–3; 17, 3–4; 18, 4–5; 19, 5–6; 20, 6–7; 21, 7–8; 22, 8–9; 23, 9–10; 24, 10–11; 25, 11–12; 26, 12–13; 27, 13–14; 28, 14–15; 29, 25–26; 30, 35–36.

FIGURE 4.—COMPARISON OF CHEMICAL COMPOSITION OF VARIOUS CRUDE OILS AND HYDROCARBONS FROM THE GULF OF MEXICO WITH THAT OF THE HYDROCARBONS AND ASPHALTS FROM CEDAR CREEK BOG.

(Erdtman, 1943, p. 11), and this portion of the organic matter along with that derived from the lipoids may have contributed to the aromatic fraction of these samples. There is some question, however, whether lignin can be decomposed under water (Ruttner, 1953, p. 172) since it is attacked predominantly by aerobic fungi which do not commonly occur in water. A source of terpenes, which have the general formula C_nH_{2n-4} and are like the aromatics in having only carbon atoms in the ring structure (homocyclic) but are more saturated, is the sap of coniferous trees; pinene, $C_{10}H_{16}$, the principal constituent of turpentine, is the commonest natural terpene (Conant and Blatt, 1947, p. 531). Waksman (1936, p. 231) reports up to 25 per cent of benzol- and alcohol-soluble material in old pine needles, which may be related to aromatics and terpenes in composition.

Most of the benzene residues were heavily loaded with tiny needle-like or platy crystals. In general the aromatic crystals are much smaller than the paraffinic crystals and show

lower-order birefringence; the needle crystals have parallel extinction. Such aromatic compounds as naphthalene and anthracene are crystalline at room temperatures and may be present in the crystalline substance found in the aromatic cuts.

Asphaltic Fraction

This forms up to 44 per cent of the lipoids and up to 2 per cent or more of the entire sample; the high value occurring in the 1–2 foot depth. The asphaltic residues varied more than did either of the hydrocarbon cuts. This variation between samples in color, viscosity, and odor is probably more important from the point of view of the origin and stratigraphy of the deposit than the actual quantity of asphaltics in individual samples. For instance, the samples which contained many *Daphnia* and other chitinous arthropod exoskeletons produced very sticky asphalt residues.

The asphaltic fraction differs strikingly from the saturated and aromatic hydrocarbons in that it is darker brown and green, weakly or not at all fluorescent, and lacks disseminated crystals. There may be an inverse relationship between the coarseness of texture of the peat and the ratio of hydrocarbons plus asphalts to the remaining lipoids (Fig. 3); the sapropelic and copropelic fractions tend to have the larger proportions of polar substances remaining on the alumina.

Relationship of Present Samples to Crude Oils and Hydrocarbons of Other Places

The chemical composition of several types of crude oils has been given by Sachanen (1945, p. 421–426). Sachanen's analyses are plotted in Figure 4A after combining his paraffin and naphthene percentages to provide a comparison with the present analyses. Chromatographic analyses of hydrocarbons from the Quaternary of the Gulf of Mexico, determined by Smith (1952, p. 438) are also plotted in Figure 4A. The Cedar Creek Bog analyses are plotted in Figure 4B. Except for the sample at the base of the peat (No. 24), the Cedar Creek samples are all highly asphaltic, resembling such deposits as the asphalt from Bermudez Lake, Venezuela. The aromatic content of the Cedar Creek samples, however, is similar to that of several high-grade crude oils. The samples studied by Smith from cores and bottom samples taken in the Gulf of Mexico average more saturated hydrocarbons than those from Cedar Creek Bog.

Post-Depositional Movements of Hydrocarbons

The lighter liquid and gaseous hydrocarbons that may have been present in the samples were not detected. That such materials might have been in the samples is suggested by the experiments of Davis and Squires (1954) who were able to obtain ethane, propane, ethylene and propylene in glucose fermentation. In eutrophic lake and bog deposits large quantities of methane are produced, a large proportion of which escapes into the air. It has been observed in sampling various lake bottoms that large bubbles of methane come to the surface when the sediment is disturbed; on the other hand, no methane was detected in the test holes in Cedar Creek Bog. The gas is evidently pushed out of the sediments during compaction (Jamin effect).

The variable distribution of the lipoid compounds in the samples studied is mainly primary, resulting both from original differences in the source material and in the rate and amount of decomposition. Subsequent movement of the oils and waxes probably results from water movements, but some migration may be effected by expulsion of the gases. The water movement may be principally of two kinds: upward expulsion of the mobile lipoids as emulsion with the water during compaction; and lateral movements along separation planes within the flexible mass of peat and marl. The entire bog surface fluctuates to correspond with seasonal precipitation (Buell, 1941, p. 317), and the accompanying movement of water in the bog is probably more lateral than vertical.

Chemical and Biochemical Stability of the Bog

In the pond in Cedar Creek Bog Lindeman (1941b) found the following range in conditions: oxygen 0–150 per cent of saturation, pH 6.8–9.4, total alkalinity 38–107 mg/l., calcium

31–92 mg/l., magnesium 7–17 mg/l., iron 0.2–20 mg/l. He found this a highly productive pond; the ratio of producers to consumers is 70.3:8.3, as expressed in calories per square centimeter.[4]

The firm portions of the bog away from the small pond are at present fairly stable judging from the mildly oxidizing Eh values obtained (Table 1). Beneath the pond, there is bacterial activity at the anaerobic level as evidenced by the somewhat reducing Eh values found there in midwinter 1954. Lindeman (1942a, p. 1) found that anaerobiosis prevailed in the bottom waters of the pond for 51 days in midwinter 1940. The reducing capacity of the sediments collected at station 4 just beneath the lake was sufficient to reduce 2 milliequivalents of N 1/10,000 methylene blue dye at room temperature, but the deeper samples did not reduce 2 milliequivalents of dye. The average temperature of the deeper parts of the bog below 10 feet was 10°C in August 1953. The hydrocarbon analysis of the sediment just beneath the lake shows no appreciable variation from the other copropel samples (Table 4).

The present stability, however, would disappear if the water table were lowered so as to drain the bog. Removal of the neutralizing humic acids and partial aeration of the bog would result in an increase in bacteriological decomposition, in evolution of CO_2, and in acidity of the bog. Growth of acid-forming *Sphagnum* under partially aerated conditions would also increase the acidity of the surface portions of the bog. The acids, called "sphagnol", possibly phenols, (D. B. Lawrence, Dept. of Botany, University of Minnesota, personal communication), are formed by *Sphagnum* and can lower the pH of the surface portions of the bog to 4 around the *Sphagnum* growth centers. In highmoor bogs the abundance of *Sphagnum* maintains high acidity in the peat accumulations even at depths of several feet, but in wetter lowmoor peats the *Sphagnum* acids are neutralized or diluted at a depth of only a few inches. According to Lawrence, the *Sphagnum* growth centers of Cedar Creek Bog form little thin islands of low pH in the otherwise somewhat alkaline bog.

The iron-rich marl at the base of the bog is highly unstable under atmospheric conditions. The iron oxidizes and the sample changes from black to light yellowish brown when dried at room temperature. The sample from 35–36 feet at station 2 contained 15.63 per cent total iron (Table 4) which appears to be siderite ("peat siderite"), but some of it may be ferrous sulfide hydrate. The Eh of this material measured at room temperature is poorly poised but gives the strongest reducing intensity of any of the samples; the total bacterial activity, however, is not great, as only one milliequivalent of N/10,000 methylene blue dye was reduced by the sediment. The pH, despite the high marl content, was only slightly alkaline, perhaps owing to the sulfur and iron compounds, and it varied owing to poor buffering.

Succession in the Bog

The following is a modification of Lindeman's (1941a) discussion of the development of the bog. The origin of the lowermost sideritic, copropelic, marl layers of the deposit is not entirely clear. The organic matter, which must have been derived principally from phytoplankton, yielded relatively small amounts of paraffinic and moderate to large amounts of aromatic hydrocarbons (Table 3). The high concentration of siderite in the basal layers suggests that there was no well-developed or consistent overturn of the lake waters; otherwise much of the iron, in absence of high organic content, would be oxidized and precipitated as limonite (Ruttner, 1953, p. 76). On the other hand, a considerable amount of the iron may have been introduced by ground water. Maintenance of a low O_2 concentration in the bottom waters results in the accumulation of iron carbonate in

[4] Birge and Juday developed the so-called bomb-calorimetry values used by ecologists, as follows: carbohydrate 4100 cal/gm, protein 5650 cal/gm, fat 9450 cal/gm. The food-group populations of individual lakes as determined in gm/m² dry weight are converted to cal/cm² by use of factors ranging from .261 to .600 for various food-groups (Lindeman, 1941b, p. 661). This method differs from that used by Roelofs (1944) who, for an index of productivity, compared plant yield in pounds per acre to nutrient content (P, K, Ca, and Fe) of the water. Roelofs found that lake bottoms in Michigan consisting of a mixture of organic matter (probably as copropel) and marl were the most productive of benthonic plants—30 per cent higher than that of marl bottoms.

the bottom sediments, especially in cold water lakes of Order 1 type (Welch, 1952, p. 63) and in the meromictic type (Thienemann, 1915). In the latter a semipermanent saline hypolimnion may form beneath the temperature hypolimnion and prevent complete overturn.

which in turn passes into a cedar forest containing *Sphagnum* hummocks. In the middle of the bog marl deposition continued almost up to the bottom of the present pond.

A hypothetical curve of the rate of deposition within this bog is given in Figure 5.

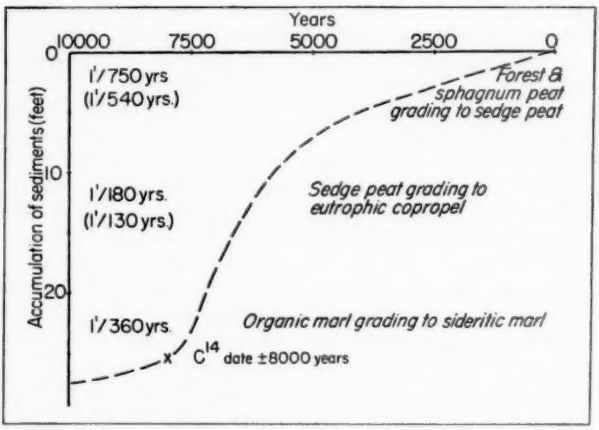


FIGURE 5.—HYPOTHETICAL CURVE OF RATE OF DEPOSITION BENEATH STATION 1, CEDAR CREEK BOG
Figures in parentheses indicate deposition rate when moisture content of peat is reduced to that of marl (65%).

A typical eutrophic phase of the marl-forming type set in above a depth of approximately 25 feet. This was marked by rapid deposition of phytoplankton under partly reducing conditions to form a mixture of copropel, sapropel, and marl in the epilimnion zone. The thin layer of dark-brown copropel (Fig. 2) may represent some climatic variation in which the deposition of coprogenic material exceeded that of marl (Lindeman, 1941a, p. 109). This copropel zone may represent temporary deepening of the lake caused by a rise in water table and resulting in development of a hypolimnion where marl formation was inhibited. The hydrocarbons formed in the marly portion of the bog were derived principally from finely particulate phyto- and zooplankton, modified by activity of benthonic worms, larvae, and crustaceans.

Above a depth of 11 feet at station 1 the eutrophic lake gradually passed into a bog, the plants of which encroached upward and outward until at present there remains only a small pond, surrounded by a quaking sedge bog

TABLE 5.—APPROXIMATE TONNAGES PER ACRE FOOT OF VARIOUS EXTRACTABLE MATERIALS IN CEDAR CREEK BOG

	Total lipoids	Total hydrocarbons	Total asphalts	Polar compounds
Peat, copropel and sapropel	86	14	18	56
Marl	26	4	7	15

QUANTITY OF EXTRACTABLE MATERIAL

Table 5 gives the approximate amounts of lipoids, hydrocarbons, asphalts, and polar-oxygenated extractables in the peat and in the marl, based on averages of figures given in Table 3, and using values of 68 lbs./ft.^{3} for the peat and 92 lbs./ft.^{3} for the marl. These are based on the figures for moisture content given in Table 2, rounded off to the nearest ton. A specific gravity of 0.9 is assumed for the lipoid materials.

Conclusion

Cedar Creek Bog contains the following deposits and associated lipoids in ascending sequence: (1) thin basal sideritic marl having about 1.5 per cent lipoids; (2) copropelic and sapropelic marl averaging 1.5 per cent lipoids, more than 30 feet thick in the middle of the deposit; (3) fine textured copropel and sapropel averaging 6.5 per cent lipoids and up to 10 feet thick in a zone peripheral to the thickest marl; (4) sedge peat and overlying forest peat averaging 6.3 per cent lipoids and thickest in a belt peripheral to that having the thickest copropel and sapropel. The highest per cent of lipoids in individual samples at station 1 was found at 4–5 feet where pollen is abundant, and at 10–11 feet just above the marl.

The 10–11 foot sample also contains the highest per cent of the saturated hydrocarbon fraction of the lipoids. The sample containing the largest aromatic fraction is at 8–9 feet at station 1 in copropel and sapropel which otherwise is similar to the adjacent material. The fine textured copropel and sapropel contains slightly more polar organic substances other than hydrocarbons and asphalts.

Although knowledge of source and process of hydrocarbon formation is incomplete, the evidence definitely points toward a contemporaneous accumulation of the hydrocarbons, other lipoids and bog sediments. An important step in the genesis and liberation of hydrocarbons from the plants may be the maceration and partial breakdown of the larger molecules in the copropel zone by the action of browsing and predatory snails, worms, and many arthropods. The environment of the hydrocarbon accumulation here is mildly alkaline with pH range from 7.1 to 7.8, low intensity of oxidation potential in the stable parts of the bog (+125 to +445 mv), and slight reducing intensity beneath the lake in the more active parts of the bog (+167 to +299 mv), with relatively small reducing capacity in the deeper parts.

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UNIVERSITY OF MINNESOTA, MINNEAPOLIS, MINN.

MANUSCRIPT RECEIVED BY THE SECRETARY OF THE SOCIETY, MARCH 30, 1954

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 65, PP. 1199-1224, 6 FIGS., 2 PLS. DECEMBER 1954

MARINE GEOLOGY OF NORTHWESTERN PACIFIC: DESCRIPTION OF JAPANESE BATHYMETRIC CHART 6901

By Robert S. Dietz

Abstract

This paper is a geological discussion of the northwest Pacific, to accompany the Japanese Hydrographic Chart 6901 (a bathymetric chart of the northwest Pacific) which is presented as Plate 1. A special edition of this chart was published under an arrangement made by the writer between the Japanese Hydrographic Office and The Geological Society of America in the belief that it will provide useful topographic data in a previously little-known portion of the sea floor and that it will stimulate further interest in Pacific marine geology. A comparison of the land surface with the sea floor, both of which are contoured at 500-m intervals, emphasizes the variety of sea-floor features and the grand scale of this submerged topography where erosional leveling is subdued.

The region covered by the chart can be divided into (1) the Pacific Basin proper, (2) the Philippine Sea Basin, including the arcuate ridges extending from Japan to Palau, and (3) the submerged portion of the Asia continental block, including the continental shelf and slope and the encompassed "intra-continental" basins. Large-scale undulations or swells and swales of low relief are the dominant structures of the Pacific Basin, but the five great groups of seamounts are the most striking features. A study of the original soundings shows some abrupt changes in level and grabenlike depressions which probably mark fracture zones in the earth's crust. The seamounts are considered to be volcanoes, many of which are capped with coral. Smooth bottom characteristizes most of the Basin, suggesting a thick sedimentary blanket. Two of the seamount groups (the Emperor Seamounts and the Magellan Seamounts) are entirely submerged; another group pierces the surface at only two places (Marcus I. and Wake I.); the Caroline and the Marshall-Gilbert groups form numerous atolls. A large number of the seamounts have deeply submerged flat-topped summits and, thus, are guyots or tablemounts. However, because of the low seismicity and the rarity of raised islands, the Pacific Basin is considered a stable area, and the sinking of the guyots is thought to be a local isostatic subsidence in response to the load of the seamounts.

The Philippine Sea Basin is bounded by the Asia continental block on the west and by the great geanticlinal ridges, extending from Japan to Palau, on the east. Trenches, presumably marking downbuckles in the earth's crust, lie seaward of these ridges. These geanticlinal ridges are active belts surmounted by volcanoes and a string of raised islands. The Kyushu-Palau Ridge, another large geanticlinal ridge, bisects the basin. Soundings give little evidence of guyots on any of the ridges or in the Philippine Sea. The Daito Mountains, nested between the Kyushu-Palau Ridge and the Ryukyu Trench, are probably orogenic rather than volcanic. The Philippine Sea Basin appears to be non-sialic and a region with normal Pacific crustal structure which has been deformed by the same compressional forces that have affected the margin of Asia.

The continental slope, marking the boundary of the Asia sialic block, extends from Kamchatka, along the Kurils, Japan, and the Ryukyus to Formosa, and probably along the east side of the Philippines. Extensive featureless shelves with shelf-breaks at normal depths fringe China and Siberia. The continental slopes are canyoned and irregular in detail. In the Okhotsk Sea there is a remarkable deep terrace which is probably a subsided normal shelf. The Kuril Basin, the Japan Sea Basin, and the Ryukyu Basin are similar abyssal pear-shaped basin within the continental framework. *En bloc* drifting of the associated island arcs, opening up simatic pools in the continental block, may account for these basins. Their smooth bottoms suggest that they are sediment traps for a great amount of sediment eroded from Asia.

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Introduction

This paper was prepared to accompany the Japanese Hydrographic Office's Chart 6901, *Bathymetric Chart of the Northwestern Pacific* which is presented as Plate 1. This chart shows, in greater detail than ever before, the geomorphology of about one-sixth of the Pacific Ocean sea floor—an area about three times as large as that of the United States. In the same manner that a topographic chart is a necessary prerequisite to geological work on land, an adequate bathymetric chart is a necessary precursor to the development of marine geology and geophysics. The configuration of the sea floor is the foundation upon which the future superstructure of the marine sciences will be raised. In 1939, Chart 6080, a chart similar to 6901 but based on fewer data, was published by the Japanese but, because of war-time conditions, only 100 copies were printed so that the existence of the chart was almost unknown to scientists inside as well as outside Japan. It is hoped that, by placing this special edition of this chart in the hands of earth scientists through the medium of this Bulletin, scientific consideration of problems of the Pacific sea floor will be greatly stimulated.

The writer has prepared the paper with the object of (1) making the chart more useful by indicating the method of construction, limitations of the sounding data, etc., (2) describing the salient features, and (3) presenting a few ideas concerning the marine geology of the region. At the outset, the writer planned mainly to present the Japanese point of view, but a search of the literature has revealed few papers concerning the larger problems of the Pacific sea floor. However, H. Niino has written extensively regarding the shallow seas around Japan, and R. Tayama and S. Hanzawa have published many papers on the islands of the northwestern Pacific Ocean.

This paper was prepared while the writer was a Fulbright Research Scholar in Japan during 1953. Through the courtesy of Dr. K. Suda, Chief of the Japanese Hydrographic Office, he was permitted access to the original sounding data on which the chart is based. This, of course, permits a much more critical analysis of the bathymetry than can be obtained by a study of the contoured chart alone because in drawing a contour map there are an infinite number of solutions.

At the writer's request the Japanese Hydrographic Office published this revised and

Anglicized edition of 6901 at cost of materials for The Geological Society of America in the interest of promoting closer scientific co-operation between the U. S. and Japan. The writer is responsible for some of the Anglicizing and for a few contour changes in the present edition but nothing more. The compilation of the data and the preparation of the chart is based on the efforts of many persons at the Japanese Hydrographic Office over many years. S. Miyamoto, T. Okawa, and K. Sumita were in charge of the 1939 version, while T. Okawa and N. Furumoto were in charge of the 1951 Chart 6901.

Hess (1948) published a geological interpretation of the U. S. Hydrographic Office's Chart 5485, which displays the bathymetry of the Philippine Sea and adjacent waters and covers about one-third of the area of 6901. The reader is referred to this excellent paper for a treatment by modern concepts of many of the larger problems of the northwestern Pacific.

Acknowledgments

The work for this paper was done at the Japanese Hydrographic Office where many facilities were provided. At this office, Kanji Suda, Chief, and A. Irahara were most helpful. Sherman K. Neuschel, Charles G. Johnson, George Viele, and Helen L. Foster of the Tokyo office of the U. S. Geological Survey supplied many valuable criticisms and suggestions. Many facilities of that office including its numerous translations of Japanese papers were made available. The writer discussed many of the problems with various Japanese geologists. Especially helpful were S. Hanzawa of Tohoku University, H. Niino of the Tokyo College of Fisheries, and H. Kuno, T. Sakamoto, and T. Kobayashi of Tokyo University. At the U. S. Navy Electronics Laboratory in San Diego, California, the writer's colleagues, H. W. Menard, E. L. Hamilton, R. F. Dill, and Geo. Shumway, read the manuscript and made valuable suggestions. To these persons and organizations the writer is most grateful.

Construction of the Chart

Excluding the shallow seas which are well sounded, Chart 6901 is based on about 100,000 deep-sea soundings, using a contour interval of 500 m (270 fathoms). About half the soundings are from Japanese sources and the remainder from foreign sources, mainly from the U. S. and Great Britain. Sounding data up to 1945 are included. The Japanese Hydrographic Office has obtained almost no new deep-sea soundings since the end of World War II. The great majority of soundings are sonic, but some wire soundings are included. All the soundings are entirely lines of spot soundings; echograms from graphically recording echo sounders of modern design have played no part in the construction of this chart. Echo sounders are customarily calibrated for a velocity of sound in water of 4800 feet per second which is almost always slightly less than the average velocity of sound along a vertical path in the deep sea. The chart was constructed using these uncorrected soundings because hydrographic charts are constructed primarily as an aid to navigation. Thus, a ship taking soundings can compare its observations directly with the chart. However, it should be borne in mind that the sea floor of the deep Pacific actually is somewhat deeper than shown on charts by as much as a few hundred meters. Table 1 gives an approximation by which the true bottom depth can be obtained. However, few of the soundings, such as the CHALLENGER depth, are corrected soundings.

Soundings are never uniformly dispersed over a bathymetric chart but rather are plentiful along shipping lanes and sparse elsewhere. Thus the bottom is known in detail along these lines of communication so that many features can be delineated. The contourer generally is reluctant to extrapolate between two widespread sounding lines, and he has a subjective tendency to draw contours either normal to or parallel to a line of soundings. Thus trends of highs and depressions develop along shipping lanes. These, of course, are fictitious insofar as having any structural significance. On Chart 6901 such fictitious trends can be noted extending from the Philippine Islands to Guam and toward Hawaii and on the great circle route directly to Hawaii. All trends which line up with shipping lanes should be regarded with suspicion.

The interesting method of contouring by using a combination of white and dark-blue lines on a blue background was developed by

Prof. K. Tanaka of Kyushu University. This permits positive and negative relief to be readily distinguished. The illusion is obtained that sunlight is falling from the northwest so that each feature has a sunlit and a shaded side. As with an aerial photo, the chart must be viewed with the shadow falling toward the observer or a reversal of relief may result. It is worth while noting that the illusion can be obtained in shades of gray—*i.e.*, with a white and black contour line on a gray background—so that a color plate is not a necessity. The method should find wide use in bathymetric presentation for it is, for most purposes, superior to showing depth by shades of blue or by hachuring depression contours. For example, attempting to use hachures for showing depressions on bathymetric maps is especially perplexing because if sea level is used as the datum plane nearly all contours become depression contours.

TABLE 1.—PERCENTAGE CORRECTION TO BE ADDED FOR CONVERTING ECHO-SOUNDER DEPTH TO TRUE DEPTH IN THE PACIFIC OCEAN

For echo sounders calibrated at 800 fms/sec (Heck, 1926).

Latitude	Fathoms								
	600	1200	1800	2400	3000	3600	4200	4800	5400
	Meters								
	1097	2194	3292	4389	5486	6584	7681	8778	9875
60° N.	0.0	0.5	1.1	1.9	2.5	3.2	3.9	4.5	5.1
55° N.	0.3	0.8	1.3	2.0	2.6	3.2	4.0	4.6	5.2
50°–40° N.	0.6	1.0	1.5	2.0	2.6	3.3	4.0	4.6	5.2
35° N.	1.3	1.4	1.7	2.2	2.8	3.4	4.1	4.8	5.3
30° N.–40° S.	2.0	1.7	2.0	2.5	3.0	3.6	4.2	4.9	5.4
45° S.	1.3	1.4	1.7	2.2	2.8	3.4	4.1	4.8	5.3
50° S.	0.6	1.0	1.5	2.0	2.6	3.3	4.0	4.6	5.2
55° S.	0.3	0.5	1.1	1.7	2.3	3.0	3.7	4.3	4.9
60° S.	0.0	0.1	0.7	1.5	2.1	2.7	3.5	4.1	4.7

The scientific usefulness of a bathymetric chart is considerably enhanced if the soundings are shown on which the contours are based. Even when the soundings are so numerous that it is impossible to place them on the chart, their location indicated by a small dot is helpful in interpreting the contours. However, this often is not practicable and was not done on Chart 6901. Figure 3 was therefore prepared; it shows the number of the soundings deeper than 200 m by 5-degree squares. Thus the deep seas near Japan and especially to the south are comparatively well sounded; the Philippine Sea, the great undersea ridges, and the atoll regions are moderately sounded; but, in contrast, soundings are sparse in the great basin north and east of Japan. The deep trenches are everywhere poorly sounded because only the most recent echo sounders have been able to obtain good echo returns from these great depths. The shallow seas are well sounded except for the Sea of Okhotsk, so the number of shallow soundings are not shown in Figure 3.

GENERAL DESCRIPTION

General

Inasmuch as the land is contoured in the same manner as the ocean floor on Chart 6901, a direct comparison of the topography can be made. Because of the small scale of the chart, only large topographic features show up. It is immediately apparent that the greatest topographic features of the earth's surface lie submerged. The largest subaerial escarpment in this region is the east side of Formosa, but this is not impressive when compared to the enormous escarpments beneath the sea. The large swells and ridges of the sea floor also are without counterpart on land. High mountains rise above New Guinea, Celebes, Luzon, central Japan, and Kamchatka. But, again, these are small when compared to the great seamounts which rise from the ocean bottom. At least 150 seamounts already are known to rise more than 2500 m above their surroundings, whereas only 35 such mountainous areas are present on the land. The more subdued topography of the land, of course, at least in part, reflects the strong leveling action of running water. The greater irregularity of the land contours also results from stream erosion as well as from detailed contouring. Erosion, which plays an all-important role in the creation of sharp relief and the ultimate destruction of elevation on land, operates on a greatly reduced scale on the ocean floor.

The zero contour line or shore line is, of

course, best known and is delineated in greatest detail. Especially in the East China Sea and in the Okhotsk Sea a great expanse lies between the shore line and 500-m isobath which closely marks the edge of the continental block. The continental shelf, although the best-surveyed submerged area, clearly stands out as the most featureless region on the chart. The known levelness of shelves may be one reason for the widespread but obviously false belief that the ocean basins are also monotonously flat.

The largest-scale topographic features of the sea floor are the basins and the swells or rises. The swells are gentle, broad, and elongate elevations of the crust 200–300 miles across and many hundreds of miles long. Such swells should not be confused with ridges which are narrow and abrupt elevations. The axes of the major swells are shown on Figure 5. Features of this great size must be in isostatic balance, and their relief probably reflects differences of density of the earth's crust. The orientation of the major swells appears to be generally east-west. Seamounts appear to be concentrated on the swells although none have been discovered on certain of them. Thus, it may be more accurate to say that the seamounts are absent from the basins.

The northwest Pacific contains two basins of the unusually great depth of about 6000 m (Fig. 4). One of these can be termed the Northwest Pacific Basin, using this term in a restricted sense. It occupies the entire east-central portion of the chart and is the deepest of all ocean basins. The other lies beneath the western half of the Philippine Sea and can be termed the West Philippine Sea Basin. There are no other large regions of comparable depth anywhere.

Examination of sounding lines permits a determination of the roughness of the bottom such as cannot be gleaned from the chart. The Philippine Sea Basin, for example, shows a continuous series of ups and downs indicating a bottom that is rough in detail. In contrast, the basins between the groups of seamounts are characterized by smooth bottom suggesting a depositional plain. The basin enclosed by the semicircular Magellan Seamounts is especially noteworthy for its smoothness. However, the smoothness of the deep-sea basin is not comparable to that found in the intracontinental basin such as the Okhotsk Sea Basin and the Bering Sea Basin. The Bering Sea Basin is remarkably flat over at least its southern portion at 3720 m.

Deep-Sea Sediments

Many exploring vessels such as the TUSCARORA, CHALLENGER, NERO, ALBATROSS, and CARNEGIE have collected bottom samples from the northwestern Pacific Ocean. The most extensive collections, however, were made by the Japanese ship, MANSHU, which collected about 700 bottom samples. These have been charted and briefly described by Hanzawa (1928). Deep-sea deposits can be classified into hemipelagic, which have a large percentage of land-derived sediments, and pelagic sediments, which are composed of the remains of pelagic organisms, chemical precipitates, and products of deep-sea weathering. The former include blue muds and sands, volcanic muds and sands, and calcareous muds and sands; the latter include the inorganic deep-sea sediments known as red clay and the organic oozes such as globigerina ooze, radiolarian ooze, diatom ooze, and pteropod ooze. All these sediment types are present in the northwestern Pacific (Fig. 6).

Blue mud, composed largely of blue, gray, or green terrestrial detritus with an admixture of some pelagic material, fringes the land areas. It is generally found down to a depth of 4000 m, coating the continental slopes and extending out for some distance on the deep-sea floor where it gradually passes into red clay. Also, this sediment type is found in all the shelf-locked basins such as the Japan Sea Basin.

Volcanic muds and sands, composed largely of lapilli, pumice, and volcanic glass, are extensively developed on the submarine ridges which bear volcanic islands such as the Mariana Ridge, the Ryukyu Ridge, the Kuril Ridge, and the Aleutian Ridge, and also in many areas along the Philippines and the East Indies. Volcanic sediments are also commonly recorded in many of the trenches.

Calcareous muds and sands, composed of the broken remains of calcareous algae, corals, mollusks, etc., cover the flanks of the coral atolls and are also found along warm-water

coasts where the deposition of inorganic detritus is slow.

By far the most widespread pelagic deposit is red clay; it covers most of the area of Chart 6901 in depths greater than about 4000 m. It shows a gradual transition into blue mud toward the land masses and into globigerina ooze toward the tropics and toward the large rises of the deep-sea floor. As well as being the dominant sediment in the Pacific Basin proper, it covers most of the floor of the Philippine Sea Basin.

Globigerina ooze, composed dominantly of the tests of pelagic Foraminifera, covers large tracts in the tropical and subtropical regions. The most extensive deposits are developed on the rises of the sea floor on which the Caroline and the Marshall Islands are developed. Typically the low-latitude regions at depths less than about 4300 m and the higher levels of the sea floor such as the tops of seamounts are covered with globigerina ooze.

Radiolarian ooze, a sediment composed of more than 20 per cent remains of the siliceous parts of radiolarians, appears to be present only in the trench off Guam. The world's greatest belt of radiolarian ooze is found in the eastern Pacific beneath the Equatorial Counter Current where its flow is intense; however, no radiolarian ooze is reported by Hanzawa (1928) from beneath the Counter Current in the western Pacific.

Pteropod ooze, composed largely of the calcareous shells of pelagic mollusks, is rare in the northwestern Pacific. It is reported by Hanzawa (1928) from only one locality in the Ryukyu region at 24°25′N. and 123°03′E.

Diatom ooze, composed of the siliceous frustules of robust types of diatoms and typically a high-latitude sediment, is reported from a few samples north of 41°, but red clay appears to be the more common sediment type. However, bottom samples are sparse north of about 35° so that it is as yet unknown if a broad band of diatom ooze spreads across the north Pacific as it does in high southern latitudes. Hanzawa (1935) has reported *Ethmodiscus* diatom ooze from 3 low-latitude localities in the western Pacific. This unusual sediment type, unknown elsewhere in the world, differs from high-latitude diatom ooze in that the latter is composed dominantly of the frustules of *Coscinodiscus*. Menard (1953) has recently shown that glacial marine sediments are widely distributed in the Gulf of Alaska, but there is no evidence of their presence in the northernmost western Pacific.

Faults on the Sea Floor

Many of the sounding lines with closely spaced soundings were plotted and studied for topographic features which might reveal crustal structure. For example, some sounding lines show an abrupt rise, marking a persistent new level of the sea floor. Such an escarpment may mark a major fault zone. Interpreting structure from topography has serious limitations, but, in the absence of stream erosion, the topographic expression of sea-floor structures can be expected to persist. As evidence of this, echograms may reveal "text book" examples of tilted fault-block mountains. An attempt must always be made to avoid accepting features which may be "artifacts"—*i.e.*, the result of human or instrumental errors.

The possible faults identified are plotted on Figure 5. They are shown by a straight line when the strike can be determined or by a circle with a cross in the center when the fault is revealed on only a single sounding line so that the strike is unknown. The faults shown generally are based on a steplike rise in the sea floor. Some are revealed by troughs which appear to be grabens. Such fracture zones are shown by a line with two arrows pointing inward. Many of the faults have a generally east-west strike. A discussion of the nature of the faulting is beyond the scope of this paper and, of course, would be highly speculative as the data are few. There are, undoubtedly, numerous faults on the sea floor which new surveys with modern echo sounders would reveal.

Of special interest is the discovery of a trough near 12°N. and 139°E. which may be a continuation of the Yap Trench into the East Philippine Sea Basin. Also, two deep en echelon troughs are present south of the central portion of the Caroline Swell, the deeper of which contains a sounding of almost 7000 m. Another trough, in the central part of the West Philip-

pine Sea Basin, has a northwest-southeast strike. Hess (1948, p. 426–428) suggested that this structure may be a part of a master rift zone extending entirely across the Philippine Sea, but the Japanese soundings reveal no other faults along the strike of this feature. Another cleft in the bottom was found near 33°N. and 160°E. on the flank of swell in the center of the Northwest Pacific Basin (Fig. 2, Profile 1).

Arcuate Structures

General

The trenches and their associated island arcs are the dominant features of Chart 6901. The arcs can be divided into two groups, the continental arcs of Kamchatka-Kuril Is.–Hokkaido, Japan, Ryukyu Is., and the Philippines, and the oceanic arcs, extending south from Japan and separating the Pacific Basin proper from the Philippine Sea.

Gutenberg and Richter (1949, p. 28–29) state that the following sequence of structures and attendant phenomena are typical of Pacific arcuate structures: (1) a trench or foredeep, (2) shallow earthquakes and negative gravity anomalies in a narrow belt on the concave side of the trough; generally, the ocean bottom rises here to a ridge with emergent small non-volcanic islands, (3) maximum positive gravity anomalies and earthquakes at a depth near 60 km, (4) the principal structural arc (Late Cretaceous or Tertiary), with active or recently extinct volcanoes with quakes at depths of about 100 km, (5) a second structural arc with older volcanism, and (6) a belt of shocks at depths of 300–700 km.

It is now widely believed that the fundamental structure of arcs is the tectogene or a downbuckle of the earth's crust into subcrustal material. Kuenen (1936) and Griggs (1939) have shown by model experiments that less energy is required to fold the earth's crust inward than outward. Geanticlinal ridges appear to form on the active or concave side of the downbuckle which develops directly beneath or slightly on the concave side of the trench. The trench will remain as long as the crust is under horizontal stress but rises isostatically into an alpine mountain range if the stress is relieved. Presumably a downbuckle of suboceanic crust will have less buoyancy than one of continental material, owing to the absence of a sial layer, so there may be less tendency for the formation of alpine mountains in ocean basins.

Trenches

The great circum-Pacific belt of trenches reaches its maximum development in the region covered by Chart 6901. The deepest places in the world are found in this region including the Challenger depth (10,863 m) near Guam, the Cape Johnson depth (10,479 m) in the Philippine Trench, and the Ramapo depth (10,680 m) in the Japan Trench. Obtaining accurate sounding in these great depths is difficult so that the presently determined depths may not stand the test of later critical surveys.[1] The trenches are still poorly sounded because only the most modern echo sounders can record the greatest depths; ships over the deeps are almost invariably "off soundings". But it is almost certain that if deeper spots are found anywhere in the world they will be discovered in this region. Also, the trenches probably have a simpler form than shown on Chart 6901. Some of the sills shown between the deep spots in the trenches and some of the irregularity, especially of the Mariana Trench where soundings are conflicting, undoubtedly will be eliminated by future surveys.

Only the western end of the Aleutian Trench appears on Chart 6901 where it intersects the Kamchatka Ridge. However, the soundings do not preclude the possibility that the Aleutian Trench continues on to meet the Kamchatka Trench. It certainly extends farther west than presently indicated because the 1953 Trans-Pacific Expedition of Scripps Institution of Oceanography discovered that it was still strongly developed at 53.5°N. and 168.0°E. with an axial depth of 3660 m.

A series of connected trenches is strung from Kamchatka to Palau, a distance of almost 4000 miles (throughout, reference is to nautical

[1] As a case in point, three crossings of the Ramapo Deep were recently made with an Edo echo sounder by the Spencer F. Baird of the Scripps Institution of Oceanography, but the greatest depth found was 4995 fms uncorrected which is 5250 fms or 9607 m corrected by Table 1. Thus considerable doubt is thrown on the validity of the USS Ramapo's determination.

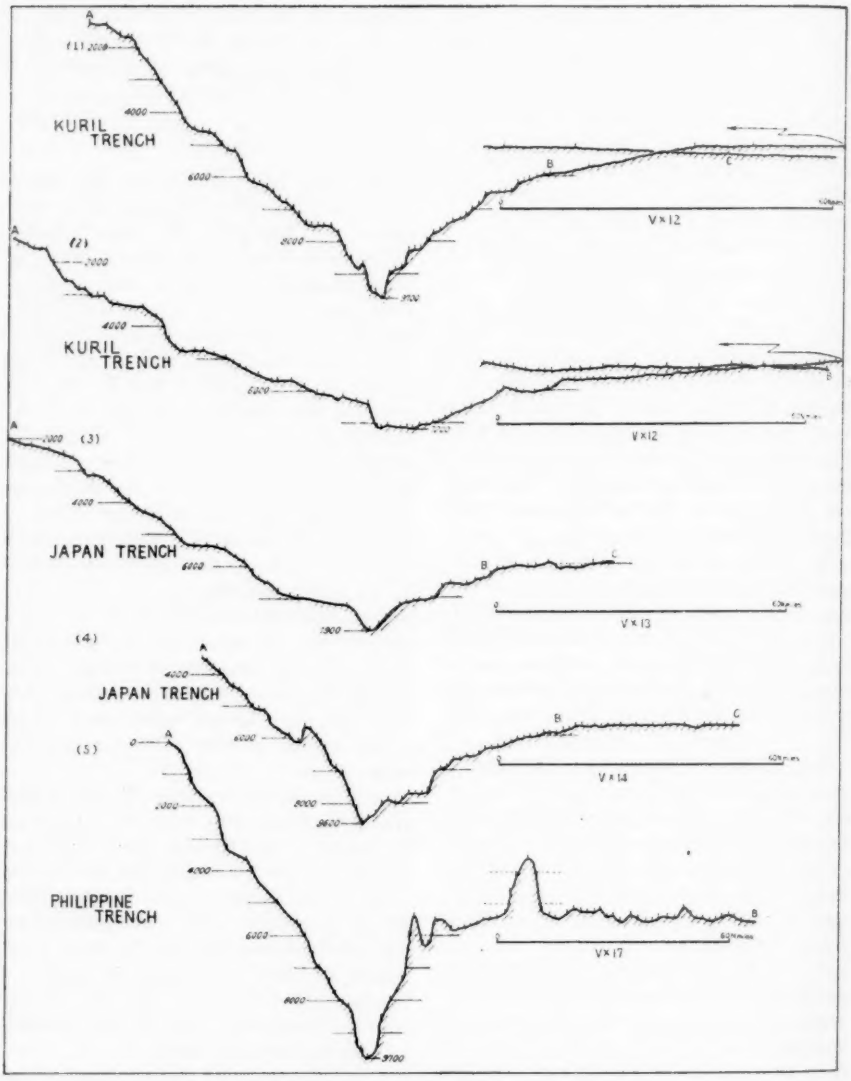

FIGURE 1.—SOUNDING PROFILES ACROSS TRENCHES

miles). Although the trench is, in a general sense, continuous, it is broken into a series of arcuate segments which intersect one another at sharp angles. From north to south these trenches are the Kamchatka Trench, the Kuril Trench, the Japan Trench proper off Honshu, the Izu-Bonin Trench, the Mariana Trench, the Yap Trench, and the Palau Trench. On the west side of the Philippine Sea lies the great Philippine Trench and the weakly developed Ryukyu Trench. The Ryukyu Trench extends along southern Japan, but here the relief is only 500 m.

Five trench profiles are presented in Figure 1.

In cross section they are check-shaped, having a steep landward slope and a gentle seaward slope. The bottom of the trench is commonly narrow. As a case in point, the Danish oceanographic vessel, GALATHEA, had difficulty remaining over the axis of the Philippine Trench while attempting to dredge the bottom (A. Bruun, personal communication). Unpublished data of R. Fisher from the Trans-Pacific Expedition shows that the bottoms commonly are flat indicating considerable sedimentation.

In plan, the arcuate form of many trenches is well known—*e.g.*, the Aleutian Trench closely approximates the arc of a circle with a radius of curvature of 750 miles. The Mariana arc has a radius of curvature of 400 miles and almost completes a semicircle. This led Lake (1931, p. 150) to suggest that they represent the intersection of a low-angle thrust plane with the earth's spherical surface, but this idea has not been widely accepted. Hess (1948, p. 441) compares the form to that developed by plastic or pseudo-viscous flow—that is, like the curving lines that traverse a glacier. The check-shaped profile with the deepest point immediately at the base of the steep landward slope is consistent with the idea that the landward side is being shoved out over the sea floor.

In connection with the weak development of the Ryukyu Trench, Hess (1948, p. 421–422) has made the interesting suggestion that it belongs to an earlier period of deformation—being formed in the mid-Mesozoic whereas the others came into existence at the end of the Mesozoic. He suggests that it is a remnant of a once-extensive trench system which is now mainly above sea level—extending from Kamchatka, through the "backbone" of Hokkaido, across Honshu and Kyushu, thence along the present Ryukyu Trench into Taiwan, thence through Luzon and Palawan in the Philippines (Fig. 5). As evidence he cites a chain of peridotite intrusions which he believes are intruded only into tectogenes and only shortly after the initial buckling.

The seismicity associated with the trenches of the western Pacific is extremely strong and is part of the great circum-Pacific seismic belt. The zone extending from central Honshu to Kamchatka is the world's most seismically active region. A major bifurcation in the circum-Pacific belt occurs in central Honshu with major activity extending down the Honshu-Mariana-Palau Ridge and lesser activity extending along southern Japan and the Ryukyu Arc. Almost all activity is associated with the arcuate structures. The Pacific Basin proper is a region of seismic calm although some strong shallow shocks are found near the western part of the Caroline Swell. Large tsunami or seismic sea waves commonly result from earthquakes along the trenches, suggesting abrupt changes of earth level of much greater magnitude than are observed on the land.

A not previously recognized aspect of trenches is the presence of a broad low swell on the oceanic side of many of them. Such a swell is developed from Japan to Kamchatka and also on the outside of the southern part of the Philippine Trench. The nature of the swell can be seen in the west portion of Profiles 1 and 2 of Figure 1. This type of swell was first noticed by the writer in connection with the trench off Baja California.

Trenches invariably cut across other structures and are not themselves interrupted, indicating their great structural importance and/or that they are young structures. A striking aspect of the arcuate structures south of Japan is that they abruptly cut off the seamount groups. This is especially marked in the case of the Caroline Group because it is transected where it has maximum development.

Honshu-Mariana Ridges

Two great ridges rise behind the trenches extending south of Japan. These can be termed the First Honshu-Mariana Ridge, extending from the Izu Islands through the Volcano Islands to the Mariana Islands and to a little south of Guam, and the Second Honshu-Mariana Ridge, extending from Honshu to the intersection of the Mariana and Yap trenches and lying symmetrical to, but from 100 to 150 miles west of, the First Ridge. These ridges have the form of an inverted sickle. In the East Philippine Sea Basin, the sea floor rises with a gently upward sweep over a distance of 150 miles toward the second ridge. These ridges are clearly geanticlines and presumably are crustal waves related to the tectogene. Ap-

parently the earth's crust was deformed into two waves in front of the primary synclinal wave which collapsed into a downbuckle.

Another geanticlinal ridge, on which the Bonin Islands are developed, lies east of the northern wing of the First Honshu-Mariana Ridge. The Bonin Ridge lies close to the trench and seems to cause a displacement of the trench to the east inasmuch as it lies close to the strike of the Izu Islands portion of the Japan Trench.

The First Honshu-Mariana Ridge is more strongly developed than the second. They are slightly asymmetric, with the east slope commonly steeper than the west. The Second Ridge nowhere pierces the surface, but there are five shoal banks in the Mariana region which mark former islands now truncated by wave action. Many volcanoes are superposed on the First Ridge, and along it there is volcanic activity in the Izu Islands, in the Iwo Islands, and in the Marianas. The volcanic axis appears to lie slightly west of the structural axis, at least in the southern Marianas. Some of the seamounts resting on the Second Ridge are probably of volcanic origin, but this is not proven because there is no active volcanism.

A search of the soundings revealed no evidence of guyots (*i.e.*, excluding banks, and defining guyots as flat-topped seamounts deeper than 300 meters, thus indicating subsidence rather than merely truncation during a Pleistocene lowering of sea level). Thus, these ridges probably always have been positive elements with a persistent tendency to rise.

A search was made for the presence of a third ridge lying in the East Philippine Sea Basin and symmetrical to the other ridges but of less relief. No such ridge was discovered. The Kyushu-Palau Ridge might be considered as the third ridge, but it probably has had a separate history from the Honshu-Mariana ridges. It is discussed later.

Seamount Groups of the Pacific Basin

General

The most striking aspect of the chart is the extensive groups of seamounts, some of which pierce the surface but others of which are deeply submerged. Many of the seamounts are truly enormous as can be realized by comparing them to the highest mountain in Japan, Mt. Fuji, located 1° west of Tokyo Bay. The seamounts rising from the deep-sea floor are much larger than those which are superposed on the geanticlinal ridges and also much larger than volcanic mountains on land. This is partly due to coral reefs capping some of the seamounts but also to the absence of erosion and probably to mountain building on a greater scale than is known on land. The hydrostatic support of the water lessens the weight of the rock on the sea floor by a little more than one-third. Also a shorter magma column may be present because of the possible closer position of the sea floor to a possible world-encircling magma layer. These may be contributing factors to the large growth of submarine volcanoes.

There is almost no information on the rocks composing the seamounts. However, on the Scripps-Navy Mid-Pacific Expedition, olivine basalt was dredged from Sylvania Seamount near Bikini and from the slopes of Bikini atoll. Where the foundation rocks of the seamount are exposed above the ocean surface, as at Truk, Ponape, and Kusaie, it consists of basic volcanics. Judging from their circular plan and steep flanks, most of the seamounts are extinct volcanoes. This is probably true even though the circular form of many of the seamounts is not firmly established but rather is a result of generalized contouring of few data. Menard (in press) by surveys and dredge hauls shows the volcanic nature of similar seamounts in the northeastern Pacific. The seamounts are probably composed of volcanic rock of great uniformity and olivine or nepheline basalt are probably the dominant types.

The seamounts are not randomly disposed but, rather, are arranged in broad belts. The linear arrangement is not nearly so perfect as that which characterizes the volcanoes associated with the arcuate structures; thus, a different type of volcanism is indicated. Seamounts in the Pacific Basin usually seem to be developed on broad linear rises or swells of the crust. For this reason Dietz and Menard (1953, p. 110–112) suggested that the swells and the seamounts are genetically related. Possibly the swells develop over thermal convection currents in the earth's mantle. Tension cracks may then develop in the swell along which magma finds

access to the surface. Little is known concerning the mechanism of deep-sea volcanism so that this is a fertile field for future research. The mechanism of growth certainly appears to be different in many ways from that observed in the subaerial environment.

No deep-sea volcanic activity is known in the region of the chart, and in fact deep-sea volcanism is rarely reported anywhere in the world, probably because its detection is difficult. Shallow submarine volcanism is known in several places along the First Honshu-Mariana Ridge. An active sulfur boil is known about 50 miles west of Tinian. A second and presently active boil exists west of South Iwo Jima. An island once appeared at this spot but later disappeared. The most spectacular submarine volcanism is the activity about 200 miles south of Tokyo at Myojin Reef which has been intermittently active for at least 50 years. Most recent activity began in September 1952 and continues. As of the present writing (February 1954) an island has been formed three times only to be later destroyed. Over 100 explosions at this volcano were detected in September 1952 along the California coast more than 8000 km distant by underwater listening (Dietz and Sheehy, 1954).

Emperor Seamounts

A great linear range of seamounts dominates the northeastern portion of Chart 6901 and extends from the vicinity of the intersection of the Aleutian Trench with the Kamchatka Trench to the vicinity of 30°N. and 174°E., a distance of about 1500 miles. This entirely submerged range cannot be identified in terms of well-known geographic landmarks as, for example, in the case of the Kyushu-Palau Ridge, so that a nongeographic name is appropriate. Hence, they are provisionally termed the Emperor Seamounts, and the names of ancient Japanese emperors are applied to several of the most prominent. Soundings in this region are sparse so that the seamounts are based on few data. Future surveys will undoubtedly produce important modifications in the bathymetry shown, and new seamounts will almost certainly be added to the chain. But the present soundings are sufficient to establish the chain as a genetically related group of unusually large seamounts. The north-south trend of the seamounts is noteworthy inasmuch as northeast-southwest is the usual trend of Pacific Island chains, while an east-west trend is common for submerged structures. The southern end of the chain ties into the western end of the Hawaiian Swell with its many superimposed seamounts (Dietz and Menard, 1953, Fig. 1).

TABLE 2.—DATA ON EMPEROR SEAMOUNTS* FROM CHART 6901 SOUNDINGS

Numerical Name	Name	Least Depth (meters)	Total Relief (meters)	Depth of Flat Top (meters)
52–170	—	2976	1900	3000
51–168	—	2352	2700	—
49–169	Tenchi	1857	4300	—
46–169	Jimmu	1299	5100	1340
45–170	Suiko	1572	5000	1600
41–170	Nintoku	949	4200	960
38–171	Jingo	2194	—	—
38–170	Ojin	1848	4600	—
34–172	Kinmei	1560	4500	—
33–172	Yuryaku	300	5000	—
32–173	Kanmu	292	5200	300
30–174	—	1969	3200	—

* The 1953 Trans-Pacific Expedition of the Scripps Institution of Oceanography provided important new data on the Emperor Seamounts, but these are not incorporated into the table inasmuch as it shows Chart 6901 data. Jimmu has least depth of 1281 m (uncorrected). It is definitely a guyot with a break-in-slope at 1500 meters and a gently shoaling depth up to its top. Suiko is a large and complicated feature 60 miles across its top and has several flattened summits. The shoalest summit has a least depth of 1090 m (uncorrected). It also is definitely a guyot with break-in-slope at 1280 m followed by gently shoaling bottom up to the minimum depth. A new guyot with a depth of 1895 m was discovered south of Suiko at 43°–07′ N. and 170°–20′ E. At the north base of Jimmu from 2800 fathoms, an assemblage of volcanic gravel was dredged including angular to well-rounded pieces. The pumice may have been rafted, but the rounded gravel most likely was rounded at the top of the seamount, when it was an island, and later moved down the flank. Examination by H. Kuno shows one rounded rock to be tuffaceous shale, an angular piece to be augite-bearing hypersthene andesite, and the pumice to be hypersthene dacite pumice. This suggests that Jimmu may not be composed of volcanics of the normal intra-Pacific type.

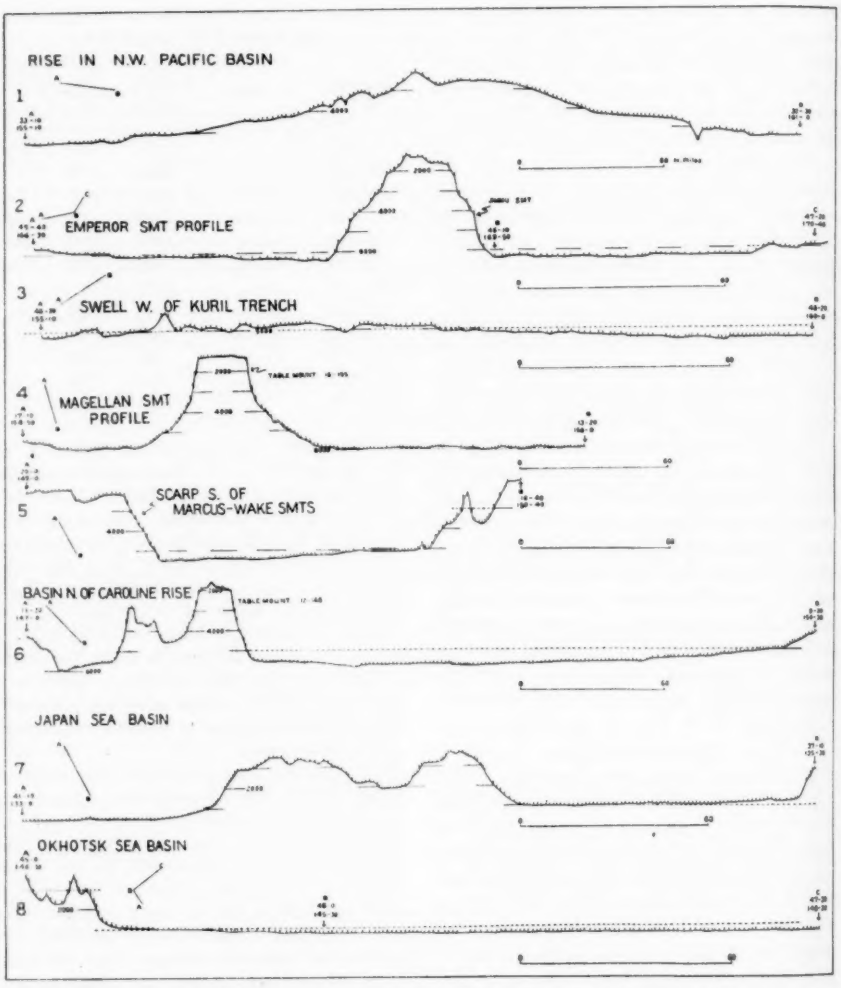

FIGURE 2.—SOME REPRESENTATIVE SOUNDING PROFILES IN THE NORTHWEST PACIFIC

At its northern end, the Emperor Seamounts connect with an extensive region of high relief termed the Komandorski Ridge. The region is sparsely sounded so that the nature of the elevated region is uncertain. The western side appears to be bounded by an abrupt and straight escarpement of 2000 m relief. On one sounding line approaching this escarpment, steplike rises of the sea floor suggest faulting.

The enormous size and relief of many of the Emperor Seamounts is striking (Table 2).

Four of them have a relief of 5000 m or more, placing them among the earth's great mountains. All the seamounts are deeply submerged except Yuryaku and Kanmu at the southern end of the chain, both of which have a summit depth of about 300 meters. However, additional soundings undoubtedly will reveal many shoaler spots than are now known. Japanese fishermen sometimes find a fish known in Japan as "menuki" in the stomachs of tuna in this region. (H. Niino, personal communication) Menuki are

bottom fish which near Japan are found at a maximum depth of 500 to 1000 m. They suggested the presence of submarine highs before such were discovered. They also suggest the presence of more shoal areas than are now known.

Five of the seamounts of the Emperor Seamounts appear to have flat tops and thus are guyots (Hess, 1946, p. 772) or tablemounts.[2] In the case of the other seamounts of the chain data are insufficient to determine whether the summits are flat or peaked. Hess (1946, p. 788–790) considered guyots to be ancient islands truncated by wave action and subsequently drowned. More recent work has tended to confirm this belief (Carsola and Dietz, 1952, p. 493; Menard and Dietz, 1951, p. 1283; Hamilton, 1953, p. 204–206). The lack of concordance in the depth of the flat tops is striking. From the Chart 6901 data Kanmu has a flat-topped depth of 300 m; Nintoku's depth is 960 m; Jimmu's depth is 1340 m; and Suiko's depth is 1600 m; and the depth of Seamount 52–170[3] is 3000 m.

All the guyots are too deep to be explained by truncation during a low Pleistocene stand of sea level because most geologists agree that the greatest lowering during the Ice Age was less than 150 m. Thus guyots indicate local or regional subsidence or drowning by a rise of sea level. There are, of course, many possible ways in which the submergence of guyots may have taken place. Hess (1946, p. 789–790), for example, considered that they are extremely ancient (*i.e.*, formed prior to the advent of reef building corals or in the Precambrian) and that their submergence is related to a slow rise of sea level caused by sedimentation in the deep sea. Hobbs (1944, p. 223–224, 260–268) suggested subsidence of the Pacific Basin as a whole. On the other hand, the present writer is inclined to favor local isostatic subsidence of large seamounts because of the great load they place on the earth's crust. Depressed zones or "moats" have been found around the base of some guyots which tends to support the latter idea (Menard and Dietz, 1951; Dietz and Menard, 1953). Soundings suggest such a moat at the base of Jimmu (Fig. 2, Profile 2).

Marcus-Wake Seamount Group

An east-west 1200-mile long broad band of seamounts is present east of the trench system and between latitudes 17° and 21°N. Only two of these seamounts pierce the surface of the sea. The group can be conveniently termed the Marcus-Wake Seamount Group. This group appears to be an extension of the submerged Mid-Pacific Mountains described by Hamilton (Ph.D. thesis, Stanford University, 1952; 1953) which begins west of Hawaii and extends to about 170°E. Only the westernmost portion of the Mid-Pacific Mountains can be seen on Chart 6901 where they are delineated as a generalized area of high relief. Like the Mid-Pacific Mountains, the Marcus-Wake Group is developed on a low swell in the ocean floor.

The seamounts are deeply submerged, generally more than 1000 m. At least some of them display flat tops and, thus, are guyots. Seamount 20–160 has an especially well-developed flat top at 1450 m. Seamount 26–145 has a flat top at 1100 m which appears to be tilted to the southeast. Seamount 27–145 rises to within 80 m of the surface. It has been surveyed in detail and displays a sharp peak, suggesting that it may be a recently formed mountain.

Several sounding lines show that the southern margin of the Marcus-Wake Group is terminated by an abrupt east-west escarpment which may mark a major fracture zone in the Pacific Basin.

Magellan Seamounts

Immediately east of the Mariana Trench, between the Marcus-Wake Seamount Group and the Caroline Group, a group of seamounts forms a semicircle with a 200-mile radius and

[2] The term "tablemount" is used in preference to "guyot" on U. S. Navy Hydrographic Office charts and is quite descriptive. However, the term, "guyot" is now well established in the literature so that it is used in this paper.

[3] In this paper unnamed seamounts are identified by their geographic co-ordinates. Thus a seamount at 25°–10′ N. and 171°–10′ E. is termed Seamount 25–171. The location of such a seamount could be more closely defined by terming it Seamount NE 25.2–171.2, thus indicating earth's quadrant and fractions of degrees. But such nomenclature is cumbersome and unnecessary if the earth quadrant is apparent and the feature is large or sufficiently isolated to be uniquely identified by listing the nearest degree of latitude.

open to the south. The name Magellan Seamounts is provisionally applied to the group inasmuch as no good geographic name can be applied and the use of historical personages is in conformance with other names in the region—*e.g.*, Caroline, Marshall, and Gilbert. Magellan, of course, was the first explorer to cross these waters en route to his discovery of the Marianas. There are at least 14 major seamounts in this group, all of which are submerged to a depth of 1200 m or more. Soundings in this region are sufficiently dense so that additional surveys will not greatly alter the appearance of this group as now known. The seamounts embrace a broad, smooth, and featureless basin at 6000 m.

This group apparently belongs to the Pacific Basin proper and is not an offshoot of the Mariana Ridge inasmuch as the west limb of the group lies tangent to the Mariana Trench rather than transecting the trench and connecting onto the Mariana Ridge. The Magellan Seamounts are thus quite different, for example, from the hook-shaped Bowers Bank Ridge in the Bering Sea Basin which is an offshoot of the Aleutian Ridge. The semicircular form of this group is noteworthy inasmuch as structures in the Pacific Basin proper generally are straight.

The three seamounts making up the east limb of the crescent are probably guyots. From north to south, the flat-top depths are 1250 m, 1500 m, and 2000 m. The 5000-meter-high northernmost seamount of the three, *i.e.*, Seamount 16–155, has a remarkably flat top about 15 miles across (Profile 4 of Fig. 2).

Seamount 17–154 appears to have an irregular summit, but the three other seamounts at the top of the semicircle probably are guyots (16–152 flat at 1300 m, 17–153 flat at 1200 m, and 18–151 flat at 1800 m). The seamounts along the western limb are deeply submerged and are connected by a continuous ridge. Here they lie tangent to the Mariana Trench and possibly have been depressed by the formation of that foredeep. Seamount 12–148, at the base of the western limb, is a guyot with a flat top at 1800 m.

Marshall and Gilbert Seamount Group

The Marshall Islands form a broad band of seamounts extending from 5°N. to 15°N. and are near the eastern margin of the chart. The Gilbert Islands form a southern tail on the Marshalls. Here, as in the other groups, the seamounts have a strong "family" resemblance. Most of these seamounts reach the surface where they form coral atolls of low relief. Foundation rock is nowhere exposed, and only Quaternary coral-reef formations are present. Like most of the other island chains in the central Pacific, the Marshalls and Gilberts display a northeast-southwest trend. The marine geology of the Marshall Islands is described in considerable detail by Emery, Tracey, and Ladd (in press). They describe several guyots. Chart 6901 is based on few soundings in this region so that the bathymetry is poorly portrayed.

Age of the Pacific Basin Seamount Groups

As noted earlier the Pacific Basin seamount groups almost certainly are volcanic rather than orogenic mountains. On the continents the development of any particular volcanic mountain chain is confined to a short geological time span. It is reasonable to assume that this is also true for sea-floor volcanic chains. Thus, if the age of a single seamount can be determined, its age may roughly date the entire group.

Beginning with the Mid-Pacific Mountains (whose western end only is shown on Pl. 1) a well-integrated mid-Cretaceous (Aptian to Cenomanian) reef coral-rudistid fauna has been dredged from two guyots (Hamilton, Ph.D. thesis, Stanford University, 1952; 1953, p. 204–205). Fossil pelagic Foraminifera of late Paleocene and early Eocene age have also been recovered from the summits of three of these mountains. Olivine basalt was dredged along with the reef fauna so that the fossil reefs apparently were in immediate contact with the volcanic foundation rock. Thus, these particular volcanoes, and probably the Mid-Pacific Mountains in general, are pre-Aptian to Cenomanian. The fact that faunas of the same age were recovered from two widely separated tablemounts strongly supports the concept of synchronous volcanism. It appears likely that the seamounts pierced the surface of the ocean, were truncated by wave action, and then were covered by a spot growth of reef coral, all in mid-Cretaceous time. However, of course, the foundation rock cannot

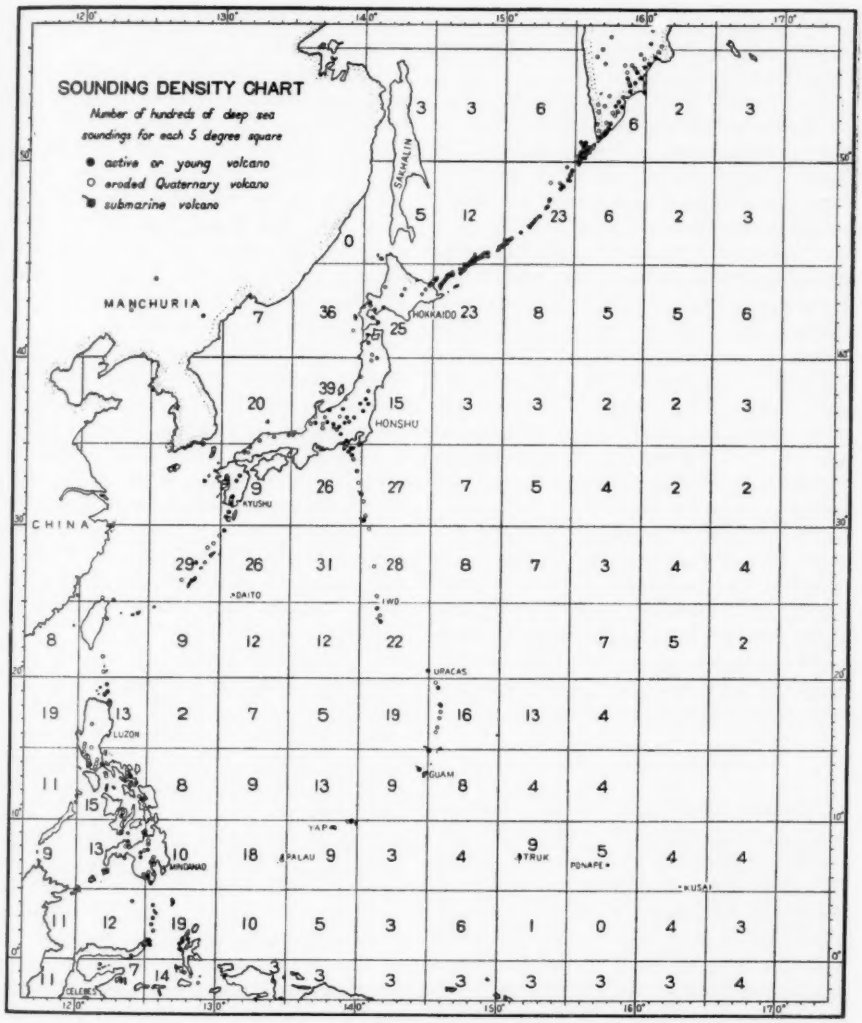

FIGURE 3.—SOUNDING DENSITY CHART

be definitely dated by the overlying reef limestone.

The Marcus-Wake Seamount Group appears to be a western extension of the Mid-Pacific Mountains. Many guyots of the two groups are deeply drowned to a similar depth of about 1800 meters. Hence the Marcus-Wake Group may be of the same age as the Mid-Pacific Mountains. Future dredging on the tops of the guyots or drilling of a well to the foundation rock on Marcus Island or Wake Island is needed for proof.

The Marshall Islands and the Gilbert Islands are mostly composed of atolls although some guyots are also known, and the two groups probably have a similar history. Recent drilling on Eniwetok Atoll has revealed Eocene in contact with the olivine basalt foundation at 4154

(Ladd *et al.*, 1953). This suggests an early Tertiary age for the volcanoes of the Marshall and Gilbert Islands.

The Caroline Islands appear to be the youngest of the seamount groups. Deeply submerged guyots are not known to be associated with the group. Volcanic islands still persist at Truk, Ponape, and Kusaie. These islands are deeply eroded and weathered. Miocene fossils have not been found, so S. Hanzawa (oral communication) considers them to have been produced by Pliocene volcanism. Thus, one may tentatively assign a late Tertiary age to the Caroline Islands.

There are few data on which to venture a guess regarding the age of the Emperor Seamounts. However, Seamount 52–170, in the axis of the Aleutian Trench, may be the northernmost member of this chain. Although there are only a few soundings, they suggest a flat top so that this seamount is probably a guyot with an unusually great platform depth of 3000 m. The unusually deep drowning of this guyot may be accounted for by the formation of the Aleutian Trench which probably originated in the late Cretaceous (Hess, 1948, p. 421). The guyot must have been in existence prior to the formation of the trench.

Philippine Sea Basin

The nearly 400,000 square miles of Philippine Sea Basin is bounded on the west by the southern half of Japan, the Ryukyu Island, and the Philippines and on the east by the arcuate seafloor ridge from Japan to the Palau Islands. This abyssally deep basin is cut into an east and west basin by the Kyushu-Palau Ridge. The east basin is somewhat shoaler, and it rises gently toward the Honshu-Mariana Ridge. The west basin is unusually deep, and, although regionally level, sounding lines show that it is rough in detail, suggesting the absence of a thick sedimentary blanket.

The Philippine Sea Basin differs from the Pacific Basin proper in the absence of very large seamounts. However, a region of rugged topography which can be termed the Daito Mountains lies at the north end of the West Philippine Sea Basin, nested between the Ryukyu Trench and the Kyushu-Palau Ridge. The mountainous area is largely submerged, but two peaks pierce the surface, one to form N. and S. Daito Island and the other to form Oki ("Outside") Daito Island[4]. A well drilled on N. Daito Island in 1934–1936 to a depth of 432 m encountered shallow-water coral-reef limestones not older than late Oligocene, but the foundation rock was not reached by the drill (Hanzawa, 1940). Cole (Ladd *et al.*, 1953, p. 2277), who also has studied these cores, places the bottom as lower Miocene. Thus, considerable subsidence and a mid-Tertiary or older age is suggested for the Daito Mountains.

The Daito Mountains are well sounded for a deep-sea region, but the soundings are not accurately positioned; thus many of the soundings are conflicting. Nevertheless, it is clear that the topography is complex and different from that of the mountain groups in the Pacific Basin proper. Large northeast-southwest ridges dominate the structure of the Daito Mountains and suggest that, in contrast to the Pacific Basin seamount groups, this is an example of an orogenic mountain range where volcanism has played only a minor role.

In geological literature (*e.g.*, Stearns, 1945) the belief is sometimes expressed that the Andesite Line which is generally drawn along the trench axes of the seawardmost trenches marks the true boundary of Asia and that the region inside this line was formerly a continent. On Chart 6901 the area thus considered by some persons as continental is essentially that occupied by the Philippine Sea Basin plus the Honshu to Palau ridges. Gutenberg and Richter (1949, p. 26, 57–58) state that a "continental structure" is indicated for the Philippine Sea by the velocity of shallow earthquake waves which cross it. These writers apparently mean that a crustal layer of intermediate or "sial-sima" composition overlies the sima ("ultra-sima" of some writers). They do not imply the former existence of a continent in this region but only that it is non-Pacific Basin from a crustal-structure point of view.

Bathymetrically, a sialsima layer extending over a large region should be indicated by shoaler bottom. The Philippine Sea Basin east

[4] Chart 6901 is in error in the labeling of S. Daito Island which should read Oki or "Outside" Daito Island.

of the Kyushu-Palau Ridge generally is about 500 meters shoaler than the deep Pacific, suggesting the presence of a thin low-density crustal layer or of sedimentary fill, but the region west of that ridge is one of the deepest expanses of ocean floor in the world. Large irregular blocks of high relief such as those present in the Japan Sea Basin, which might be interpreted as sialic remnants of a continent, are absent from the Philippine Sea Basin.

There are no reports of granitic outcrops or granitic xenoliths, which would suggest a sialic foundation, in the lavas of the islands along the eastern margin of the Philippine Sea. The andesites on these islands are considered by Kuno (oral communication, 1952) to be of the "pigeonitic rock series" and thus to have been produced by fractional crystallization from a basaltic magma rather than by sialic contamination which produces a "hypersthenic rock series" according to this writer. The crystalline schist on Yap is sometimes referred to as "continental rock", but there is no compelling evidence to show that it is not a metamorphosed oceanic sediment. All in all, the argument for the existence of a former continental mass in the region of the Philippine Sea is not convincing. However, the forces that have buckled Asia and fragmented the continental margin have extended out to sea to form the oceanic ridges extending from Honshu to Palau. This is ample reason for considering the Andesite Line as marking the limit of the Pacific Basin proper from a structural point of view even if not in terms of crustal composition.

Islands

General

The islands of the northwestern Pacific can be classified as (1) marginal continental islands, (2) islands on the submarine geanticlinal ridges, and (3) islands rising from the abyssal sea floor. The continental islands are those lying inside of the continental slope from Kamchatka to Japan and thence to Formosa, the Philippines, and New Guinea. Many of them are large and geologically complex. Their geology is related to that of Asia rather than to the Pacific Basin, so no discussion of them is necessary here.

Except for Parece Vela Reef on the Kyushu-Palau Ridge and the volcanic Bonin Island on the Bonin Ridge, all the geanticlinal islands are confined to the First Honshu-Mariana Ridge. The Second Honshu-Mariana Ridge is devoid of islands although several shallow banks are known. The island groups surmounting the first Honshu-Mariana Ridge, from north to south, are the Izu Islands. the Volcano Islands, the Mariana Islands, the Yap Islands, and the Palau Islands.

The seven islands of the Izu Islands are volcanic, and several of them are active. South of the Izu Islands lie the Volcano Islands or North, Middle, and South Iwo Jima. A submarine volcano is presently active near South Iwo Jima. The northern Marianas are volcanic islands of andesitic composition. Uracus is presently active, but others are extinct. The southern Marianas or Saipan, Tinian, Aquijan, Medinilla, Rota, and Guam are composed of Tertiary limestone, and all show terrace topography. These limestones are elevated coral reefs or the upper Eocene and upper Oligocene which, in turn, are partly covered by upper Pliocene or Pleistocene limestones. Beneath the upper Eocene rocks are tuffs and agglomerates of andesites and liparites, suggesting the introduction of volcanism in the Eocene. The southern Marianas mark the emergent crest of the geanticlinal ridge. The volcanic axis of this ridge lies to the west, and two submarine volcanoes are known.

Yap is underlain by crystalline schists of unknown age. Volcanic agglomerate covering the schist contains Tertiary fossils so that the schist is Tertiary or older. The main island of the Palau Islands is composed of andesitic agglomerate containing Eocene Foraminifera and indicating Eocene volcanism. The Bonin Islands, apparently lying on a geanticlinal ridge frontal to the First Honshu-Mariana Ridge, also have volcanic rocks of Eocene age.

The islands rising from the deep-sea floor are geologically simple. Truk, Ponape, and Kusaie in the Carolines are all composed of basaltic rock. All the other Caroline Islands, the Marshalls and Gilberts, Marcus and Wake, and the Daito Islands in the Philippine Sea are Quaternary coral reefs. Inasmuch as the volcanic islands of the Carolines all lie toward the

eastern end of the group, volcanism probably has progressed from west to east. Such a probable eastward progression of volcanism is noteworthy because it is found in the Hawaiian Islands, the Society Islands, and the Revillagigedo Islands.

The above data on the islands have been mainly extracted from Hanzawa (1941) and Tayama (1952). Tayama's chart of the islands is presented as Plate 2 inasmuch as it summarizes many facts about the Northwest Pacific oceanic islands. It also demonstrates the strong family resemblance of the islands belonging to any particular group.

Raised Islands

It is common knowledge that many of the islands superposed on the First Honshu-Mariana Ridge show evidence of having been elevated (Pl. 2). This is particularly marked in the southern Mariana Islands. Bridge (1948, p. 222) has summarized the situation as follows:

> "In the southern Mariana Islands the Tertiary and early Quaternary limestones have been raised as much as 1,500 feet above the present sea level (Rota). Locally the strata have been highly tilted and the surfaces of marine terraces have been offset and tilted by faulting (Guam, Rota, Tinian, Saipan). All evidence at hand indicates that the diastrophic forces were active in the Mariana Islands throughout the Tertiary, and that they are still going on. In the Palau Islands the uplift of the Plio-Pleistocene limestones amounts to at least 700 feet (Urukthapel Islands), and in the Admiralty group, limestones presumably of the same age, have been raised at least 200 feet (Manus). The volcanic rocks upon which these limestones rest have been moderately folded and faulted, but there is no evidence of regional metamorphism in the rocks seen in either groups."

The Daito Islands in the Philippine Sea are elevated coral islands. North ("Kita") Daito Island is raised 230 feet; South ("Minami") Daito Island is raised 200 feet; and Outside ("Oki") Daito Island is raised 100 feet (Nugent, 1948, p. 979–982). According to Hanzawa (personal communication) the uplifted limestone at N. Daito Island is lower Pleistocene, and tectonic uplift probably took place in the latest Pleistocene because the limestones are only slightly weathered.

In the Pacific Basin proper, submergence has been the rule as evidenced by the drowned coral reefs, the coral atolls with thick limestones, and the guyots which almost certainly are deeply drowned islands. On Chart 6901, Fais Island, Nauru Island, and Ocean Island typical of most coral islands are the only islands which have more than the few meters of "freeboard" (Tayama, 1952). Nugent (1948, p. 983) lists Marcus Island as slightly raised, but Tayama considers it to be a sea-level coral reef. Fais Island, about 100 miles east of the Yap Trench, is a raised coral reef which has been elevated 23 meters. As pointed out, a low rise is sometimes present to the seaward of some trenches which appears to be in some manner associated with the mechanism of trench formation. Thus, uparching of the earth's crust to the seaward of the Yap Trench might account for the elevation of Fais Island although the bathymetry here is so complicated that the presence of such a rise is not certain.

Neighboring Ocean and Nauru Islands are raised 67 m and 82 m, respectively, according to Tayama (1952). This amount of elevation is too great to be accounted for by interglacial high sea levels inasmuch as estimates on the total rise of sea level, if all ice were melted, range from 24 m to 60 m (Flint, 1947, p. 437). These two isolated islands are not a part of any larger group, and they are 170 miles apart. Like the Daito Islands, they appear to have been uplifted by some regional elevation of the deep-sea floor. On the Scripps Institution of Oceanography CAPRICORN Expedition, a low ridge was discovered connecting the two islands (H. W. Menard, personal communication).

Coral Reef Problem

There has recently been a marked convergence of opinion regarding the origin of coral reefs—a result, no doubt, of the rapid accumulation of reliable data especially by drilling and by studying guyots—which has increasingly limited the realm for speculation. Of major assistance in the resolution of many aspects of the coral-reef problem has been the recognition of the different history undergone by those reefs which rest on the continental shelves, on the great geanticlinal ridges, and capping volcanoes rising from the abyssal sea floor. Chart 6901 clearly shows these differences in the structural setting of coral-reef islands.

The status of the problem has been summarized in an excellent paper by Ladd and Tracey (1949). Probably most geologists now adhere to the belief well expressed by Kuenen (1950, p. 414–479) and Tayama (1952, p. 274–276) which is a synthesis of the Darwinian concept of great drowning as the primary effect with the concept of glacial control as a secondary effect to explain many of the details of the present-day geomorphology of coral atolls. These writers also argue for extremely slow preglacial subsidence in comparison with a regional postglacial rise of sea level.

Coral reefs are sensitive "tide gauges" to past changes of sea level, and it seems that what little "freeboard" coral atolls now have is mostly due to a postglacial negative eustatic shift of sea level of 2 or 3 meters. Probably the major problem at present is the cause of the drowning. Has sea level risen or has the sea floor subsided as a whole, regionally, or as an immediate isostatic consequence to the load imposed by the reef and the extinct volcano on which it rests? The coral-reef problem, of course, is closely related to the problem of the origin of the guyots inasmuch as these are the platforms on which the Pacific Basin coral atolls rest.

Japan Sea Basin, Ryukyu Basin, and Kuril Sea Basin as Intra-Continental Basins

The Ryukyu, Japan, and Kuril arcs embrace depressions on their continental side which seem to be genetically related to the formation of the arcs. The Japan Sea Basin is by far the largest depression, extending over 150,000 square miles. It lies behind the largest arc, and it is known in the greatest detail. The Japan Sea Basin and the Kuril Sea Basin are similar geomorphic forms with an arcuate southeast side and an almost straight northwest side. They are both broad at their southwest side and become narrow to the northeast.

A "sial line" marking the boundary of the Asia continental block best can be drawn along the base of the continental slope outside the arcs extending from Kamchatka to Formosa and thence outside the Philippines and New Guinea. However, the structure of the last two named regions is too complicated to discuss here and is a portion of the East Indies structure not covered by Chart 6901. The basement geology and the submarine morphology around the Philippines has been described by Irving (1950; 1951). The basins inside the sial line—*i.e.*, inside the continental framework—might be termed "intra continental" or "hinter" basins.

Japan, of course, is a sialic block. Granite also outcrops on Kunashir Island, Urup Island, and Paramushiro Island in the Kuril Islands (Sasa, personal communication) so that the Kuril arc is probably a granitic ridge. Granite also crops out in the western Aleutian Islands, and the Bering Sea Basin is "pear-shaped" like the Japan Sea Basin suggesting that it also may be an intracontinental basin. According to H. A. Powers (personal communication) the geology of the Aleutian Islands is, in general, an extension of the Alaska Peninsula geology, and all the Aleutian-Alaska Peninsula rocks should be placed in the broad category of "sialic," even though there is a fair proportion of basaltic lava and gabbro intrusive among them. Acidic rocks are not so abundant as the basic ones, but they are widely distributed both in geologic time and in geography. Intrusive soda granite and dacite are found on Attu, dacite and rhyolite on the Rat Islands, quartz monzonite and dacites in the Andreanof Group, quartz monzonite and rhyolite on Umnak, and quartz monzonite and rhyolite on Unalaska.

Evidence shows that at least the south entrance of the Sea of Japan has been cut off in the past. Large mammals such as Pleistocene elephants have crossed into Japan indicating the existence of a land bridge. Also cold-water faunas are present in some of the Neogene strata along the west coast of Honshu suggesting that, at times, the warm Tsushima Current has not been able to enter the Japan Sea.

Niino (1935) dredged the two large banks, Yamato Tai and Kita Yamato Tai, in the Japan Sea Basin. Both banks have extensive flat tops, one at 300 m and the other at 500 m, suggesting that the banks were once islands. Rocks dredged were mostly well rounded and are of continental types resembling those found on the mainland of Japan. These highs in the basin are quite different in geomorphic appearance from those of the Pacific Basin. Terrigenous green muds and

sands fill the Japan Sea Basin, and the deeper parts are smooth and featureless indicating a considerable fill of sediment (Fig. 2, Profile 7). The greatest depth is 3610 m which is about 2000 m less than the typical depth of the Pacific sea floor. The Okhotsk Sea Basin is even smoother than the Japan Sea Basin (Fig. 2, Profile 8).

Most Japanese geologists believe the major structures of Japan can be explained best in terms of a horizontal force directed from the northwest which intermittently has been active since its beginning in the mid-Mesozoic. Folding parallel to the arcuate outline of Japan and overthrusting to the southeast, such as has occurred along the Median Tectonic Line are considered evidence of such a force. It also appears likely that Japan has been shoved *en bloc* to the southeast. A crushed and shattered zone known as the Fossa Magna extends across central Honshu and normal to the arcuate outline of Japan. The Fossa Magna, which may be thought of as the "broken back" of Japan, divides the Japanese arc into a north wing and a southwest wing. The north wing appears to have moved farther than the southwest wing forming the Fossa Magna as a compressional hinge zone (Kobayashi, 1941). The obstruction to the southeastward movement of Japan, imposed by the great sea ridge extending south from Japan, also may have played a part in the formation of the Fossa Magna.

The drifting of the Japanese arc out from Asia, and the Kuril and Ryukyu arcs as well, is one way to account for the basins behind these arcs. As the sialic blocks were pushed out, exposed pools of sima would remain in the wake, and, owing to isostasy, these sima areas would be expressed topographically as basins. Accordingly, the large banks in the Japan Sea Basin may be remnant sialic blocks. The discrepancy in depth between these basins and the simatic deep-sea floor may be accounted for by sedimentation because these basins act as great sediment traps, catching detritus eroded from a large sector of Asia. It might be argued that the basins are geosynclinal waves lying behind the arcs which are geanticlinal. However, the steep flanks of the basins are more suggestive of an abrupt change in crustal structure.

Granitic cobbles are present in a Permian conglomerate in Japan although seemingly there was no granite batholith uncovered at that time. Possibly a batholith near Vladivostok was the source of the granite and Japan was adjacent to Asia at that time (Kobayashi, 1941).

Continental Shelf and Slope

Continental Shelf Sediments

The character of the bottom sediments on the continental shelf around most of Japan and in the Yellow and East China Sea has been described and charted by Shepard, Emery, and Gould (1949). Their charts show sediment distributed irregularly over continental shelves. Sand is the most common type present on the Asiatic shelf. Along much of this coast mud predominates near shore, and sand outside. Large rock areas occur particularly along the Japanese east coast where the Kuroshio flows at high velocities. Also, the wethering of volcanic rocks provides little sand, and there are few large rivers to carry sand to the Japan shelf. According to these writers, the distribution of the sediments appears to be controlled by such factors as (1) sources (large rivers, shore erosion, organic growth, and recent volcanism), (2) currents (oceanic, tidal, and longshore), (3) waves (in exposed areas), and (4) bottom topography (topographic highs, basins, and submarine canyons).

The bottom character of the shelves around Japan recently has been charted in some detail by the Japanese Hydrographic Office because of the close correlation of bottom types with fisheries.

Submarine Canyons

As elsewhere in the world, the continental slopes in the northwestern Pacific display rough topography and are incised by many submarine canyons wherever detailed surveys have been made such as around Japan and the Philippine Islands and along the east coast of Formosa. Chart 6901 is of such a small scale that only the largest submarine canyons, such as Tokyo canyon, are delineated and then only in a very generalized form. Because of the limitations of early types of echo sounders and surveying

methods, only the shallow portions of the canyons are known in any detail, but it is apparent that the canyons do extend into deep water. At least around Japan the canyons appear to be incised in rock (Niino, 1952, p. 403–407) and to be similar to those off California described by Shepard (1941).

Shepard's (1948, Fig. 69, p. 210) world-distribution chart of submarine canyons shows these features only on continental and insular slopes. The Trans-Pacific Expedition echogram, however, shows at least three developed on the eastern slope of the First Honshu-Mariana Ridge more than 100 miles south of Japan. Only a single crossing was made, but the deep incisions made into an otherwise smooth slope leaves little question but that these are *bona fide* canyons. These are good examples of canyons which clearly have no relation to any landmass or even to shallow water.

As Kuenen (1950, p. 509) has pointed out, submarine canyons descend into the Japan Sea Basin to at least 1000 meters. But the sill depth of the Sea of Japan is shallow (140 meters), so that if the ocean level were lowered ponding would take place at this level, assuming an excess of precipitation over evaporation which is likely at this latitude. Thus, those persons who would explain submarine canyons by river cutting during a great withdrawal of the ocean are faced with a dilemma in the Japan Sea.

Some Japanese geologists consider that submarine canyons around Japan were formed subaerially and later submerged by marginal warping (Yabe and Tayama, 1929; Niino, 1943). The submarine canyon problem is too involved for discussion in this paper, and Chart 6901 throws little new light on the problem. In the writer's opinion, however, the submarine canyons of the northwest Pacific as elsewhere may ultimately be explained in terms of submarine processes.

Okhotsk Deep Shelf

The central portion of the Okhotsk Sea shelf is occupied by a large depressed area more than 300 miles square, immediately north of the Kuril Basin. This feature is of such grand proportions that it deserves special mention. Soundings are sparse in this region but suggest a smooth, featureless plain like a continental shelf except for its abnormally great depth averaging 1200 meters. Continental shelves of the world generally slope gently out to a depth of about 120 m where there is an abrupt increase in slope or "shelf-break", marking the top of the continental slope. Thus, the intermediate depressed region of the Okhotsk Sea is unusual. The northern portion of the deep shelf has areas deeper than 1600 meters, and it seems to be separated from the southern portion by a sill about 150 m shoaler. Also, the soundings seem to establish the 831-m shallow basin, 100 miles west of central Kamchatka, as a true basin with 500 m of closure. Because of its great extent, this deep shelf with its shallow basins must be of tectonic origin, being a subsided portion of a normal shelf.

Sounding lines show what may be cross sections of two leveed channels on the deep shelf, but this cannot be proved from the available data. Leveed channels are present on almost flat stretches of sea floor off California (Menard and Ludwick, 1951; Buffington, 1952; Dill, Dietz, and Stewart, 1954). Other probable deep-sea channels have been identified in the eastern portion of the Indian Ocean (Dietz, 1953) and in the Atlantic (Ewing *et al.*, 1953). Bottom-flowing turbidity currents with a density only slightly in excess of that of sea water may account for such channels. The Trans-Pacific Expedition fathogram shows one profile across what may be leveed deep-sea channel on the deep-sea floor east of Kamchatka.

Depth of the Shelf Break

By an examination of the original sounding sheets, an estimate was made of the depth of the shelf-break—*i.e.*, the intersection of the continental slope with the shelf. These depths are plotted on Figure 4. According to Shepard (1948, p. 143) the world average for the depth of the shelf-break is 75 fathoms or 137 m. Although there is considerable scatter from 40 to almost 300 m, this average depth holds good for the northwest Pacific.

It is a widespread opinion that the shelf-break marks the edge of a wave-built terrace formed at wave base and that the shelf edge is in equilibrium with either present sea level or a past

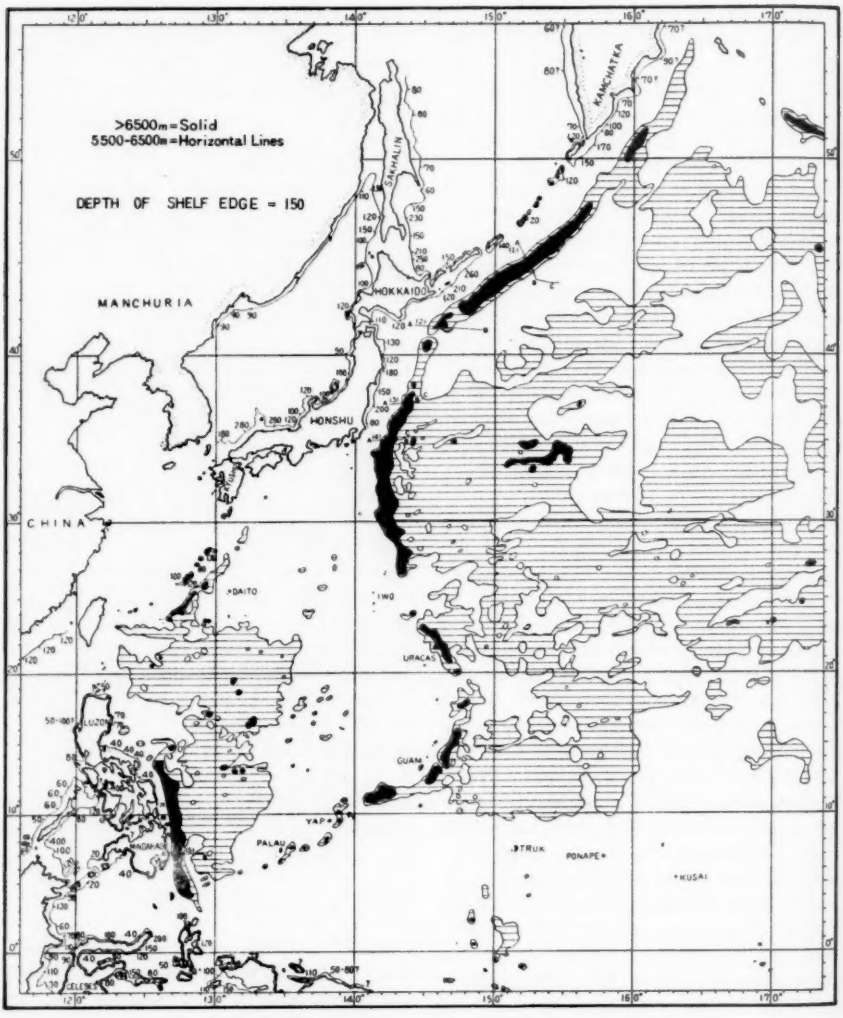

FIGURE 4.—SIMPLIFIED DEPTH CHART AND CHART OF SHELF-BREAK DEPTHS

lower sea level. However, the writer thinks the shelf edge has no connnection with wave base but that its form is due to surf-zone processes at a time of lowered sea level and its present depth is due to the postglacial rise of sea level as the primary effect and to tectonic changes of earth level as a secondary effect (Dietz and Menard, 1951; Dietz, 1952). Thus, from the study of the depth of the shelf edge in general together with the study of terrace levels on the shelf it may be possible to decipher sea-level changes since the late Tertiary. When this is understood, the departure of the shelf edge depth in a particular area from the normal depth may be interpreted as a tectonic effect. In any event, the shelf-break is an important geomorphic feature deserving careful study.

Terrace levels on the shelf may indicate past

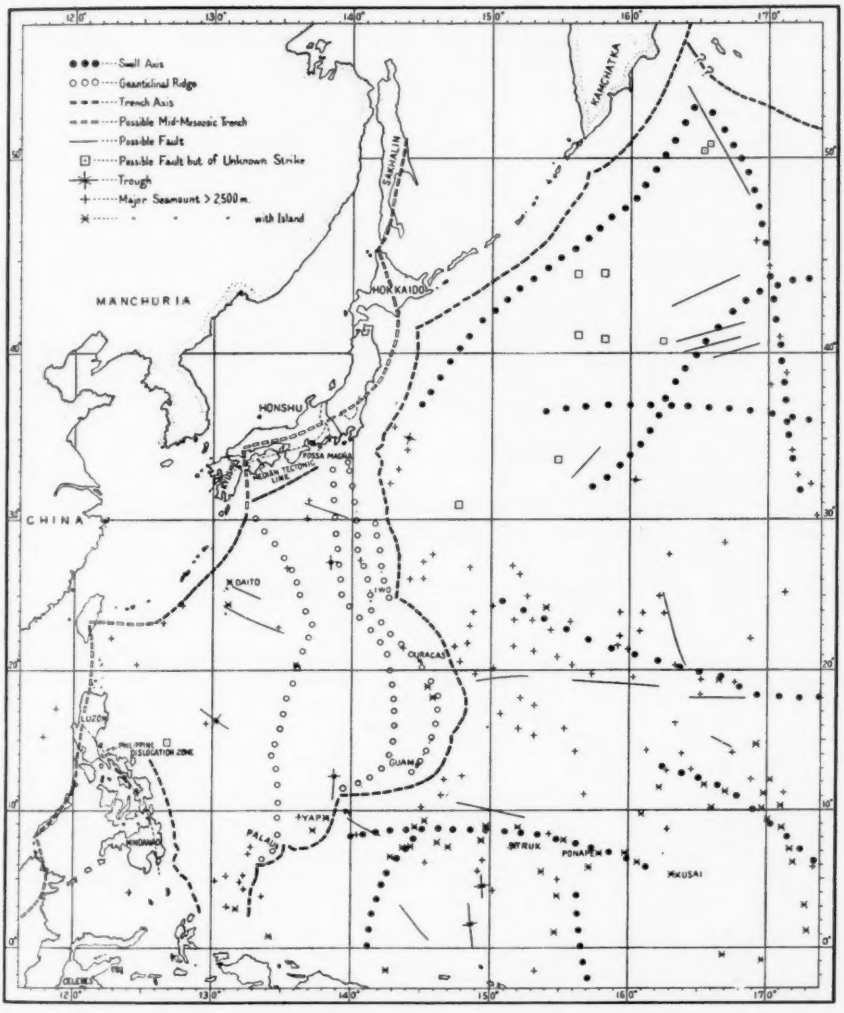

FIGURE 5.—MAJOR STRUCTURAL ELEMENTS

stands of sea level. H. Niino (Personal communication) recognizes the widespread presence of a terrace level on the shelf at minus 20 m around Japan. Such a terrace level is widely recognized in other parts of the world so that it may be related to a postglacial eustatic stand of sea level.

Around Japan Niino (1943) has collected considerable evidence that the continental shelves have been covered by shallower waters than at present and have in places been above sea level. Water-worn coarse gravel is found almost everywhere and to considerable depth. Such gravel must have been formed in rivers or in the surf zone. *Pecten tokyoensis* Tokugawa, an index fossil of the Pleistocene in Japan, has been collected as a dead shell from a depth of 120–180 m. The shallow-water fauna as-

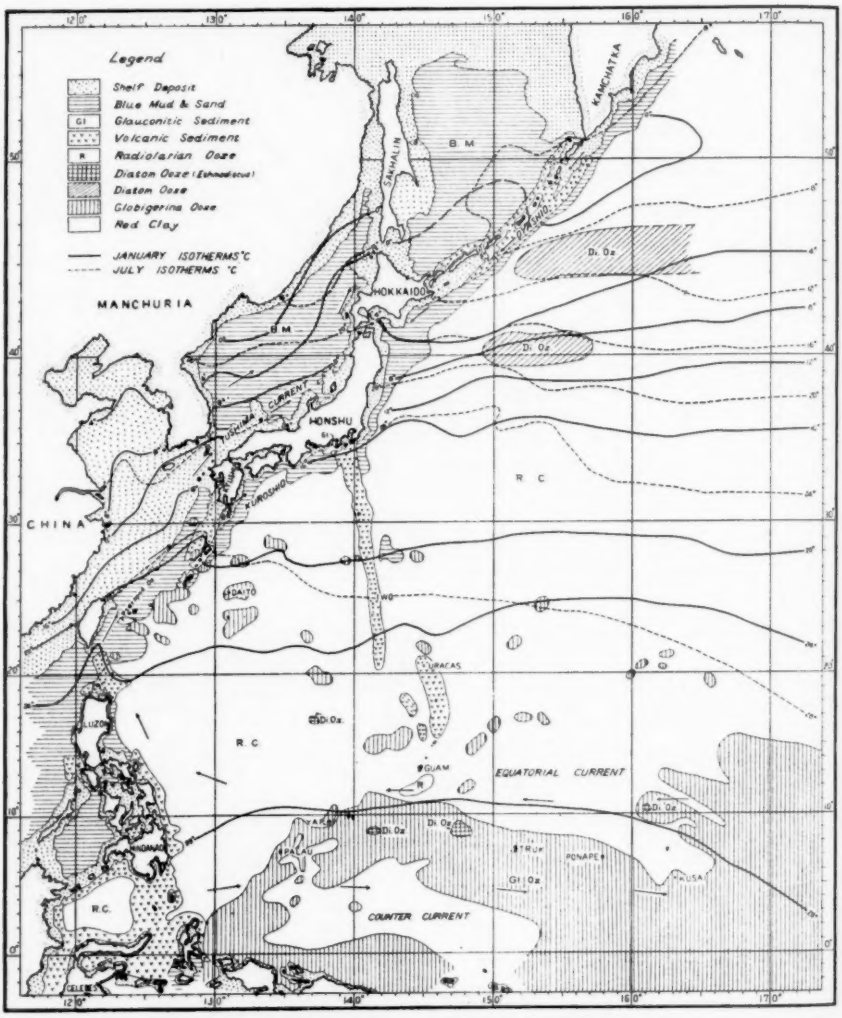

FIGURE 6.—ISOTHERM AND BOTTOM-SEDIMENT CHART

sociated with this fossil where it is found on land suggests that it lived in water less than 20 meters deep.

SUGGESTIONS FOR FUTURE WORK

Chart 6901 delineates for the first time a reconnaissance picture of the topography of about one-sixth of the Pacific sea floor. It is an important beginning which should focus attention on the deep-sea floor and stimulate research in the youthful but rapidly growing field of marine geology and geophysics.

Additional accurately positioned surveys of the sea floor are especially needed, using modern graphically recording echo sounders which obtain an essentially continuous profile of the bottom. Modern electronic equipment has now brought mapping of the deep-sea floor within the range of feasibility. Such surveys can dis-

play the profile of the sea floor in such detail as to render all previous surveys obsolete. For years to come, and until the sea-floor topography is known in considerable detail, echo sounding promises to yield the most information for the least effort and expense.

Geophysical surveys, especially gravity determinations at sea and seismic reflection and refraction work, although expensive and laborious, are much needed to solve the problems of crustal composition beneath the deep sea. Seismic studies can determine if the sima is everywhere present at a shallow depth beneath the sea floor or if layers of sial or sialsima blanket parts of the sea floor. The thickness of unconsolidated sediment can also be measured by this technique. Gravity determinations will, of course, throw light on the presence of tectogenes, the load placed on the crust by submarine volcanoes, and degree of approach to isostatic equilibrium of various regions of the ocean floor. Geophysicists also should undertake the problem of crustal yielding under a volcanic load using the data provided by those guyots which have a surrounding moat.

The successful dredging of mid-Cretaceous macrofossils and the dredging and coring of Tertiary pelagic Foraminifera from the Mid-Pacific Mountains emphasizes the importance of dredging and coring margins of the tops of seamounts. Here older rocks have not been blanketed with Recent sediment. Semi-indurated Paleocene and Eocene globigerina-ooze rocks dredged from two seamounts on the Mid-Pacific Expedition have the fresh appearance of modern material and indicate stable conditions of supersaturation of the upper waters of the tropical Pacific with respect to calcium carbonate since mid-Cretaceous. Thus, good preservation of calcareous fossil material on the sea floor appears likely in many environments. As Hamilton has showed (1953, p. 219–221) pelagic Foraminifera prove extremely useful for deep-sea stratigraphic work.

Although much bottom sampling has been done in the southern portion of 6901, there are few samples from north of 35°. Almost all the samples obtained are surface samples so that much coring needs to be done.

The Japanese have done little exploration beyond the limits of their homeland, but, with her maritime interests and her abundance of geological and geophysical talent, Japan should play a leading role in exploring the deep-sea floor of this part of the world.

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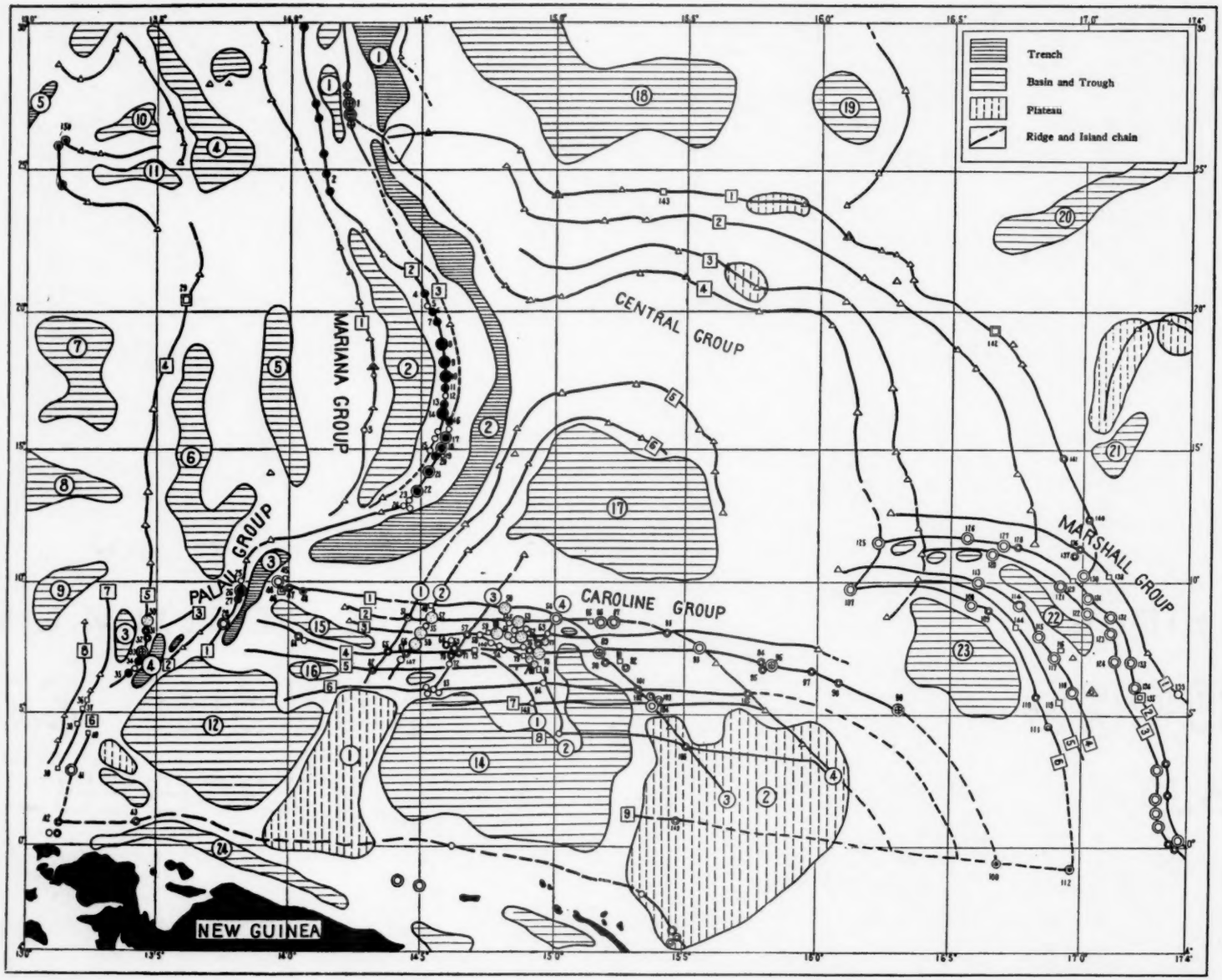
Office of Naval Research, London, Box 39, FPO 100, New York, N. Y.

Manuscript Received by the Secretary of the Society, March 24, 1954

Contribution from the Scripps Institution of Oceanography, New Series No. 644



Quaternary volcano | Tertiary volcano with reef | Raised coral I. with reef | Continental I. with reef | Large atoll | Small atoll | Almost table reef | Table reef | Submerged atoll | Submerged table reef | Submarine crest (shallower than 1,000m) | Sea mount (deeper than 1,000m)

GEOLOGY OF THE SOUTH SEA ISLANDS

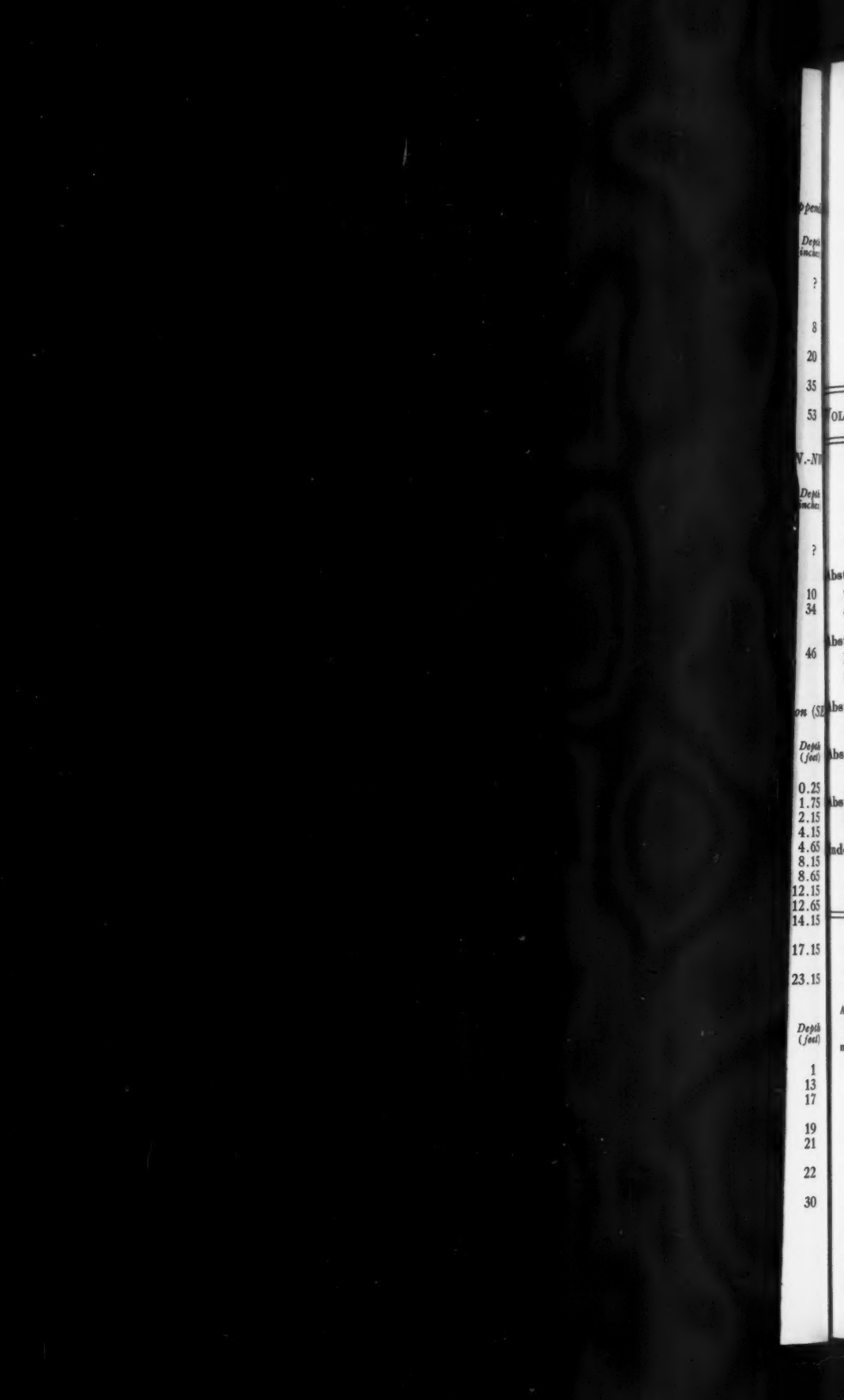
From Tayama (1952, Fig. 3)

Island, Reef and Bank

1 Ogasawara Is.
2 Yuō (Volcano) I.
3 Aragusu R.
4 Uracas I.
5 Supply R.
6 Maug I.
7 Asuncion I.
8 Agrigan I.
9 Pagan I.
10 Alamagan I.
11 Guguan I.
12 Zealandia B.
13 Sarigan I.
14 Anatahan I.
15 Esmeralda B.
16 Medinilla I.
17 Saipan I.
18 Tinian I.
19 Tatumi R.
20 Aguijan I.
21 Rota I.
22 Guam I.
23 Galvez B.
24 Santa Rosa B.
25 Hunter B.
26 Yap I.
27 Garim I.
28 Ngulu I.
29 Parece Vela R.
30 Velasco R.
31 Ngaruangl I.
32 Kayangel I.
33 Palau I. Proper
34 Urukthapel I. etc.
35 Angaur I.
36 Fana I.
37 Sonsorol I.
38 Pulo I.
39 Tobi (Tokobei) I.
40 Merir I.
41 Helen I.
42 Asia I.
43 Mapia Is.
44 Ulithi I.
45 Palaiop I
46 Losiep I.
47 Zohhouyoru B.
48 Pais I.
49 Gaferut I.
50 Mc Laughlin B.
51 Faraulep I.
52 Tarang B.
53 Mugumi B.
54 Namonuito I.
55 Akasi R.
56 Earl Dalhausi B.
57 West Fayu I.
58 Oraitilipu B.
59 Pikelot I.
60 Condor R.
61 Matuye B.
62 Gray Feather B.
63 88m-B.
64 Sorol I.
65 Woleai I.
66 Gamen R.
67 Ifalik I.
68 Olimarao I.
69 Erato I.
70 Toas I.
71 Lamotrek I.
72 Oraiuruguron R.
73 Satawal I.
74 Condor B.
75 Puluwat I.
76 Pulap I.
77 Hitchfield B.
78 Uranie B.
79 North Manila R.
80 South Manila R.
81 Pulusuk I.
82 Esuripik I.
83 Janthe Shoal
84 Lady Elgin B.
85 East Fayu I.
86 Nomwin I.
87 Murilo I.
88 Minto R.
89 Truk Is.
90 Kuop I.
91 Nama I.
92 Losap I.
93 Oroluk I.
94 Pakin I.
95 Anto I.
96 Ponape I.
97 Mokil I.
98 Pingelap I.
99 Kusaie I.
100 Nauru I.
101 Namoluk I.
102 Satawal I.
103 Etal I.
104 Lukunor I.
105 Ngatik I.
106 Nukuoro I.
107 Ujelang I.
108 Ujae I.
109 Lae I.
110 Namorik I.
111 Epon I.
112 Ocean I.
113 Wotho I.
114 Kwajalein I.
115 Namu I.
116 Jabwot I.
117 Ailinglaplap I.
118 Jaluit I.
119 Kili I.
120 Ailinginae I.
121 Likiep I.
122 Erikup I.
123 Aur I.
124 Majuro I.
125 Eniwetok I.
126 Bikini I.
127 Rongelap I.
128 Rongerik I.
129 Jemo I.
130 Ailuk I.
131 Wotje I.
132 Maloelap I.
133 Arno I.
134 Mille I.
135 Knox I.
136 Utirik Is.
137 Taka I.
138 Mejit I.
139 Keats B.
140 Bikar I.
141 Taongi I.
142 Wake I.
143 Marcus I.
144 Lip (Erippu) I.
145 Kōyō B.
146 Tarang R.
147 Ulos R.
148 Helen R.
149 Greenwich I.
150 Kitadaitō I.

Trench

1 Japan Trench
2 Mariana Trench
3 Yap Trench
4 Palau Trench
5 Ryūkyū Trench



Bulletin
of
The Geological Society of America

VOLUME 65 December 1954 NUMBER 12, PART 2

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Subscription $15.00 per year.

Printing Office: Mt. Royal & Guilford Aves., Baltimore 2, Md.

Communications for publications should be addressed to The Geological Society of America, Dr. H. R. Aldrich, Secretary, 419 West 117 Street, New York, N. Y.

Please give notice of change of address 4 weeks in advance. Claims for non-receipt of the Bulletin of a given month must be sent to the Secretary of the Society before the end of the second succeeding month.

Entered as second-class matter at the Post Office at Baltimore, Md., under the Act of Congress of July 16, 1894.
Accepted for mailing at special rate of postage provided for in Section 1103 Act of October 3, 1917, authorized on July 8, 1918.

PAPERS IN PRESS FOR FORTHCOMING ISSUES

GEOLOGY OF THE HANOVER QUADRANGLE, NEW HAMPSHIRE AND VERMONT. By John B. Lyons

A geological map of the Hanover quadrangle, in color, accompanies this paper. Separate copies of the map, unfolded and in tubes, will be available. Price 25 cents. Remittance should accompany order.

GLENDORA VOLCANIC ROCKS, LOS ANGELES BASIN, CALIFORNIA. By John S. Shelton

A geological map, in color, accompanies this paper. Separate copies of the map, unfolded and in tubes, will be available. Price 25 cents. Remittance should accompany order.

PERIDOTITE OF MANPUR, SINGHBHUM DISTRICT, BIHAR, INDIA, AND ORIGIN OF ASSOCIATED ASBESTOS DEPOSITS. By S. C. Chatterjee

GEOLOGY OF THE LIMA REGION, SOUTHWESTERN MONTANA AND ADJACENT IDAHO. By Robert Scholten, K. A. Keenmon, and W. O. Kupsch

GEOLOGY OF CATOCTIN MOUNTAIN, MARYLAND AND VIRGINIA. By John C. Whitaker

TRONDHJEMITE BATHOLITH NEAR BIDWELL BAR, CALIFORNIA. By Robert R. Compton

REGIMEN AND FLOW OF ICE IN EQUILIBRIUM GLACIERS. By E. L. Nielsen

Note: Separate copies of Japanese Bathymetric Chart 6901 (Dietz, Pl. 1 this Bulletin), unfolded and in tubes, are available. Price 50 cents. Remittance should accompany order.

ABSTRACTS OF PAPERS SUBMITTED FOR THE NOVEMBER MEETING IN LOS ANGELES, CALIFORNIA, NOVEMBER 1–3, 1954

URANIUM CONTENTS OF WISCONSIN RIVERS AND THEIR USE IN GEOCHEMICAL PROSPECTING

John A. S. Adams
The Rice Institute, Houston, Texas

More than 100 samples from 18 stations on Wisconsin rivers, including the Mississippi, have been analyzed fluorimetrically for uranium. Uranium contents from 0.01 to 1.1 parts per billion were found, with an overall average of 0.45 parts per billion. Experiments indicate an average error of ±6.4% of the amount present.

At different seasons of the year one station on the Mississippi showed unsystematic variations from 0.08 to 0.82 parts per billion, and other stations on large rivers showed similar variations. Small northern Wisconsin rivers systematically had their maximum uranium concentrations in winter; it is believed that ground water is responsible for most of the uranium in these streams. Southern Wisconsin rivers systematically had their maximum uranium concentrations in the spring; it is believed that uranium from phosphate fertilizer is responsible for this springtime peak. Analyses of representative samples of phosphate fertilizer used last spring in Wisconsin showed uranium contents from 22 to 56 parts per million, which would give uranium concentrations of about 8 pounds per square mile of fertilized land. These data and material balances based upon them are very useful in suggesting a pattern of geochemical prospecting based upon sampling ground and surface waters.

SAN ANDREAS FAULT ZONE IN SAN GORGONIO PASS, CALIFORNIA

Clarence R. Allen
Division of the Geological Sciences, California Institute of Technology, Pasadena 4, Calif.

In San Gorgonio Pass, 70 miles east of Los Angeles, the San Andreas fault is characterized by the absence of rift topography, absence of lateral stream offsets, seismic evidence for the predominance of thrusting over strike-slip movements, and an apparent discontinuity in the fault trace.

The San Andreas fault curves abruptly southward in San Gorgonio Pass and butts into the east-trending Banning fault at an angle of 45°. Post-Mesozoic lateral displacement on this part of the fault probably has not exceeded a few tens of miles, and possibly has been much less. The Banning fault, a member of the Transverse Range system, delineates the north side of San Gorgonio Pass. This break probably is older than the northwest-trending faults of the San Andreas system; its total displacement is unknown and may be large. A zone of low-angle thrusting along the Banning fault near Cabazon is attributed to local deflection of San Andreas-type lateral strain along this older east-trending fault.

North of San Gorgonio Pass, the Mission Creek and Mill Creek faults are major branches of the San Andreas fault that may have absorbed some of the lateral strain, but displacements on these faults probably have not exceeded a few tens of miles.

Structural relationships in San Gorgonio Pass suggest southeastward fraying out of the San Andreas fault, and it is still not clear whether any single break southeast of this area truly deserves the parent name.

URANIUM IN APATITE

Z. S. Altschuler, R. S. Clarke, Jr., and E. J. Young
U. S. Geological Survey, Washington 25, D. C.

Apatite contains only traces of uranium, yet as apatite is a minor constituent in most rocks and the major constituent of a few very large deposits it accounts, paradoxically, for both dispersal and concentration of uranium in nature.

Uranium is typically 0.00X per cent of primary igneous apatite and 0.00X to 0.01X per cent of sedimentary marine apatite. End-stage igneous apatite may contain 0.0X per cent uranium. Analogously, marine reworked apatite becomes enriched in uranium from 0.00X to 0.0X per cent. This is demonstrated by the greater uranium contents of the texturally more complex phases within a single deposit.

Uranium can be secondarily leached from or introduced into apatite by ground water. These secondary changes are indicated by the existence of pronounced concentration gradients within single pebbles of apatite as well as by the redistribution of uranium among different mineral hosts in leached and altered sections of phosphorite.

It is proposed that uranium replaces calcium in the apatite structure. This is signified by several lines of investigation. Uranium and calcium contents parallel one another in sections of leached and altered phosphorite. Ionic radii of tetravalent uranium (1.05 A) and divalent calcium (1.06 A) are virtually identical, and most of the uranium in igneous, sedimentary, and bone apatite is tetravalent. Petrographic and chemical analyses and nuclear emulsion studies have shown that uranium in apatite is disseminated rather than locally concentrated. In addition, phosphate deposits are essentially devoid of uranium minerals.

FACTORS INFLUENCING URANIUM ACCUMULATION IN PLANTS

Roger Y. Anderson and Edwin B. Kurtz
Department of Botany, University of Arizona, Tucson, Ariz.

In an attempt to account for the great variability in the accumulation of mineral salts by plants growing in the field, detailed laboratory studies have been made of the factors that influence accumulation with respect to uranium. Plants were grown in the greenhouse by nutrient-culture methods and analyzed by the alpha-scintillation method. Results indicate that different species vary markedly in their ability to accumulate uranium. By determining the relative ability of each species to accumulate uranium under standard conditions it should be possible to correlate among species in the field. Uranium accumulation seems to be a linear function of uranium concentration in the soil medium. Some plants increase their uranium content with age, while others decrease their content with age. In two plants the older organs contained the most uranium, but in a third plant the younger organs contained the most. Low levels of soil phosphate greatly increased the accumulation of uranium, probably by increasing the availability of uranium in the soil. High levels of phosphate delayed flowering in oats; however, high levels of uranium, which would be expected to tie up the phosphate, also delayed flowering. Other factors being studied include soil acidity (pH), transpiration, variation within the species in the ability to accumulate uranium, and mineral nutrition. Refinement of the present field methods of biogeochemical prospecting should be possible by determining the importance of each factor for each species used.

CHARNOCKITE SERIES IN BUNGER LAKE AREA, ANTARCTICA*

E. T. Apfel and W. T. Huang
Syracuse University, Syracuse, N. Y.; University of Oklahoma, Norman, Okla.

The Bunger Lake area (66° 7′ S. Lat., 100° 56′ E. Long.) of the Antarctica covers approximately 30 by 15 miles.

The rocks collected represent a wide variety of Precambrian igneous and metamorphic types. The outstanding ones are represented by the charnockite series. The acid and intermediate members of the series consist of erratics; hence their field relations are unknown. The basic member is found at the northern end of the area. Its geologic setting is known.

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* Publication authorized by the Director, U. S. Geological Survey

The charnockite series is represented by hypersthene granite, hypersthene tonalite, and members designated as norite and noritic charnockite, respectively. Contamination of some basic charnockites by granitic emanations provides a clue to the origin of the erratics, in which hypersthene may have been derived from the basic charnockites.

The mineralogical features of petrogenic significance are: (1) the paucity of water in the charnockites is indicated by mineral species, (2) an increase in the FeO/MgO ratio as evidenced by the character of the hypersthene in the more acid charnockite is in accord with the trend of crystallization in mafic magmas, (3) strong development of microperthites and myrmekite, (4) garnet occurs in hypersthene granite, while augite is confined to noritic charnockites.

In view of the similarity of occurrence, mineralogy, chemical characters, and textural features of the Bunger Lake charnockites to those of other Antarctic charnockites, it appears that these rocks were originally a differentiated series of basic igneous intrusions and have been metamorphosed during granitization. The discovery of the charnockites in this area has added a fourth distinct province to Antarctica.

MAPPING PLUTONIC ROCKS IN THE COAST RANGE OF BRITISH COLUMBIA, CANADA*

J. E. Armstrong and J. A. Roddick
Geological Survey of Canada, 300 West Pender St., Vancouver, B. C.

In mapping 500 square miles of plutonic rocks in the southwest part of the Coast Range the authors separated rock types on the relative proportions of quartz, potash feldspar, plagioclase feldspar, and mafic minerals. Commonly used classifications, in which the separation depends on composition of plagioclase, in addition to relative proportion of essential minerals, were not practicable, as the plagioclase is highly variable in composition, is generally zoned (oscillatory), and is indeterminable in the field. Wherever average composition of plagioclase was determined specimens obviously from a homogeneous mass contained zoned plagioclases with varying average compositions, necessitating several rock names for this mass if the standardized classifications were used. In mapping, although separation into five generalized rock types (granite, granodiorite, quartz diorite, diorite, and gabbro) was easy, a further division on the relative proportion of hornblende to biotite conveyed a better picture of relation of rock types to one another and to older sedimentary and volcanic formations. The plutonic rocks fall into five facies divisions (hornblende or biotite rich, hornblende or biotite predominant, and hornblende and biotite in equal proportions). Mapping with this classification developed the following conclusions: (1) Plutonic rocks containing same mafic minerals are more closely associated than those containing same relative proportions of quartz and feldspar; that is, hornblende granite and hornblende diorite are associated, whereas hornblende granite and biotite granite are not. (2) Normally the ratio of hornblende to biotite increases near areas of older strata. (3) The general trend of various facies divisions roughly parallels that of preplutonic rocks. (4) All facies are gradational into one another.

PRELIMINARY REPORT ON THE SEDIMENTS AND FORAMINIFERA FROM THE SALTON SEA, SOUTHERN CALIFORNIA

Robert E. Arnal
University of Southern California, University Ave., Los Angeles 7, Calif.

The Salton Sea is a lake of interior drainage in a large graben separated from the Gulf of California by the Colorado River delta. After the last marine invasion of the region in late Miocene or lower Pliocene time, the present basin was formed and has, periodically, been filled to different elevations

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by flood waters of the Colorado River. This is witnessed by relatively recent fresh-water lake deposits on the borders of the basin.

Following the spectacular break of its levees in 1905, the river discharged again its entire flow for nearly two years into the Imperial Valley, thus creating the present Salton Sea. Since then, intense evaporation has caused a progressive increase in salinity.

Investigations show that:

(1) The chlorinity of the water ranges from 0.70‰ to 14.20‰.

(2) Extreme readings for water temperature were 12°C and 31.5°C.

(3) Away from the shore, grain size and pH of the sediments decrease rapidly, whereas the organic carbon content increases.

(4) The foraminiferal population is typically an *Elphidium-Streblus*-miliolid shallow-water assemblage.

(5) Foraminiferal numbers (number of Foraminifera per gram of sediment) are much higher close to shore than in the center of the lake.

(6) Arenaceous Foraminifera have been found at only one station near an estuary.

(7) No planktonic Foraminifera have been collected.

Foraminifera and other small marine organisms may have been introduced into the lake in several ways, among which are: birds, naval seaplanes, transplantation of marine fishes, and speed-boating.

PARTICLE SIZES OF CLAY MINERALS BY SMALL-ANGLE X-RAY SCATTERING

Ronald J. Arnott
The Texas Company Research Laboratory, Bellaire, Texas

A review of the present methods of particle-size determination of clay minerals indicates that none is entirely adequate. Electron microscopy has provided the first reliable measure of clay sizes but gives poor results with montmorillonite and illite. This paper describes an investigation of small-angle x-ray scattering as a possible technique. The interpretation used is that of Shull and Roess involving a graphical comparison of experimental scattering curves with theoretical scattering curves. In theory, both the distribution of particle sizes and the shape of the particles should be obtainable, but in practice outside evidence of the shape is required.

A two-crystal spectrometer was used to collect data for 2 carbon black samples and 28 clay samples. The carbon blacks and most of the clays gave scattering curves from which particle-size information could be extracted. The scattering curves for the halloysites and attapulgites could not be interpreted, probably because of their fibrous or tubular character. Of five purified samples of illite and montmorillonite, four gave uninterpretable scattering curves, possibly owing to extreme orientation during treatment. Because of the scarcity of similar data in the literature it is difficult to verify the particle-size information derived. However, it is believed that the small-angle x-ray scattering technique will fill the need for a relatively simple method of determining clay sizes.

SIGNIFICANCE OF CARBONATE STRATIFICATION IN PELAGIC DEPOSITS

Gustaf Arrhenius
Scripps Institution of Oceanography, La Jolla, California

The carbonate stratification of Pleistocene and Recent pelagic deposits is of widely varying type. To evaluate the significance of the stratification it is necessary to check the relative importance of changes in (a) accumulation of detrital minerals, (b) accumulation of minerals formed inorganically in the ocean, (c) production of calcareous plankton, (d) production of noncalcareous plankton, (e) dissolution of skeletal remains of plankton. Where changes in (a) and (b) are minor, increased oceanic circulation as during the Ice Ages will result in increased carbonate content of the deposit if (c) dominates over (e). This is the case, *e.g.*, in the vicinity of the Equatorial Divergence in the Pacific

Ocean. If in the case of an intensified circulation (e) increases more rapidly than (c), lowering of the carbonate content of the bottom deposit will be the result. Lowered carbonate content of glacial strata has been observed in the Equatorial Atlantic, as well as below the Equatorial Countercurrent and in South Equatorial areas of the Pacific.

The importance of air transport of detrital minerals is being investigated. The structural distribution of boron in the pelagic Pacific clay minerals indicates that a considerable fraction of these minerals is precipitated from solution in the ocean.

The amount of calcareous material dissolved after deposition can be estimated from the concentration of the traces of insoluble material left behind. Phosphorus has been used for this purpose, and barium appears to be still more promising.

ECOLOGY OF FORAMINIFERA IN THE NORTHEASTERN GULF OF MEXICO*

Orville L. Bandy
Geology Department, University of Southern California, Los Angeles 7, Calif.

Samples for this investigation were collected inshore from 100 fathoms between Mobile, Alabama, and Fort Myers, Florida, and from Tampa Bay, Charlotte Harbor, Pine Island Sound, San Carlos Bay, and the lower reaches of some rivers, as part of the U. S. Geological Survey's study of Florida phosphate deposits.

Faunal assemblages of inshore areas are as follows: river habitat and inner shoals, *Ammobaculites* and *Streblus*; inner bays and channels, *Elphidium* and *Streblus*; intermediate and outer parts of harbors and bays, *Eliphidium*, *Streblus*, miliolids, and rare offshore species; and intermediate and outer shoals, abundant *Streblus*, few arenaceous species. Salinity variation controls distribution patterns of Foraminifera in the brackish habitat. The greatest weight percentage of Foraminifera and the greatest number of species in the sediment are in channels and open bay areas.

Offshore samples present a faunal gradation as follows:

Depth in Feet	*Brackish Areas*	*Normal Salinity Environment*
0	*Streblus* assemblage	*Archaias angulatus*
40	*Hanzawaia strattoni*	*Archaias angulatus*
	Asterigerina carinata	*Asterigerina carinata*
		Hanzawaia strattoni
105		*Planulina ornata*
		Hanzawaia strattoni
		H. concentrica
180		*Cibicides pseudoungerianus*
		Hanzawaia concentrica
		Amphistegina lessonii
250		*Uvigerina* assemblage
		Amphistegina lessonii
400		*Uvigerina* assemblage
		Bolvina goesii
600		

The weight percentage of the Foraminifera in the sediment increases gradually offshore to the edge of the continental shelf, then climbs rapidly beyond this point. The number of benthonic species increases from 20 or less near the shore to 50 or more on the upper part of the continental slope. Different upper limits of the depth ranges of planktonic species demonstrate another method of depth correlation.

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MINERALOGY AND PETROGRAPHY OF THE CHATTANOOGA SHALE

T. F. Bates, E. O. Strahl, N. M. Short, E. N. Silverman, E. Camilli
Department of Mineralogy, Pennsylvania State University, State College, Pa.

Detailed mineralogical and petrographic analysis of a drill core of the Chattanooga formation has resulted in a clearer picture of the relationship of uranium with the composition and texture of the black shale from the Highland Rim area of Tennessee.

Thin-section point counts, alpha-track counts, and quantitative mineralogical and chemical analyses of 60 samples from 35 feet of core have yielded statistically significant correlations between uranium and some of the shale constituents. The correlation is positive with respect to "blackness" of the sample, total carbon, pyrite, and total sulfur, and negative with quartz, feldspar, and clay and with Fe_2O_3. The absence of high correlation coefficients indicates that the uranium is not specific to any single constituent measured. On the other hand certain relationships between uranium content and composition are apparent.

The upper member of the formation is darkest, shows the least mineralogical and petrographic variation, and contains the highest concentration of uranium. The four lower members are more heterogeneous and consist of alternating gray and black beds. The gray beds are finer-grained and contain more quartz, feldspar, and clay and less pyrite and organic matter than the black layers.

Autoradiographic studies demonstrate that the alpha-particle source material is localized about concentrations of organic matter and pyrite.

URANIUM DEPOSITS OF THE BOULDER BATHOLITH, MONTANA

George E. Becraft and Darrell M. Pinckney
U. S. Geological Survey, Spokane, Washington

Uranium minerals have been found in the Boulder batholith in at least three structural and mineralogic environments. In several mines in the northern part of the batholith, uranium minerals in persistent shear zones cutting the quartz monzonite of the batholith are spatially associated with minerals containing base and precious metals. In discontinuous silicified zones in the quartz monzonite in the northern part of the batholith and at one location west of Butte, uranium minerals are associated with chalcedonic quartz containing sparse pyrite and very small amounts of other sulfides. The only known occurrence of uranium minerals in the Cretaceous volcanic rocks into which the Boulder batholith was intruded is at the Red Rock mine about 2 miles west of Basin, Montana, where uranium is associated with thorium and rare earths in an intensely altered and brecciated zone.

Almost all the known occurrences of uranium are in the northern part of the batholith. In Butte, only minor amounts of radioactivity have been detected scattered at random throughout the extensive mine workings, although the production of other metals there far exceeds the production elsewhere in the batholith.

UPPER MISSISSIPPI VALLEY MIDDLE ORDOVICIAN BENTONITES

W. Charles Bell
Department of Geology, The University of Texas, Austin, Texas

Two Middle Ordovician bentonites can be traced from St. Paul, Minnesota, to the margin of the Platteville mining district in Wisconsin. The upper bentonite (B) occurs about 6 inches above the base of the Spechts Ferry shale in the mining district and northwestward to McGregor, Iowa; from 1–2 feet above the base of the Decorah shale in its type area near the Iowa-Minnesota line; and about 6 feet above the base of the Decorah shale from Rochester, Minnesota, to St. Paul. This is the "putty layer" of the Twin Cities and the "pipe clay" of the Platteville district and has been correlated with the Hounsfield bentonite by Kay.

The lower bentonite (A) lies wholly within an unnamed upper limestone member of the Platteville formation from the Twin Cities almost to the Iowa line, and from there southeastward into Wisconsin lies at the base of the member—which itself thins from 7 feet in Minnesota to a feather edge in Wisconsin.

Bentonite A has been miscorrelated in Minnesota with bentonite B in Iowa, and partly in consequence the unnamed limestone member in Minnesota has been miscorrelated with the Spechts Ferry shale member of Iowa and Wisconsin. The two bentonites are 8.5 feet apart in St. Paul and converge steadily to within less than a foot of each other in Wisconsin.

If the bentonites represent planes of contemporaneity, rates of deposition during the intervening interval differed by a factor of 8 or 9 between the Twin Cities and the Platteville district.

GLACIAL GEOLOGY OF UPPER SAN JOAQUIN DRAINAGE, WESTERN SLOPE, SIERRA NEVADA

Joseph H. Birman
Department of Geology, Occidental College, Los Angeles, Calif.

Seven moraine sets occur along the South Fork of the San Joaquin River and its tributary, Mono Creek. Each set has a characteristic ratio of fresh to weathered boulders, which confirms distinction suggested by moraine morphology and degree of bedrock weathering. For convenience, moraine sets are described in three groups.

Group I, the oldest, contains highly weathered erratics and till. Original morphology has been largely destroyed.

Group II contains three sets of well-formed moraines, each with distinctive weathering characteristics. End moraines are virtually absent in the earliest set, scarce in the intermediate set, and present at about 7000-feet elevation in the latest set.

Group III contains three moraine sets mostly above 8500 feet. Distinct reversal of weathering ratio in the oldest set suggests minor short-lived glaciation long after withdrawal of Group II ice. The youngest set includes bare, unstable rock glaciers and moraines at cirque headwalls. The intermediate moraines occur as much as a mile from cirque headwalls. Abundant lichens and tree-ring counts indicate a minimum age of 250 years.

Work in upper Rock Creek and visits to other Eastern Slope canyons tentatively suggest that: (1) Group I deposits are largely Sherwin in age; (2) in Group II, the earliest and latest sets closely resemble respectively Tahoe and Tioga moraines; (3) the intermediate set of Group II occurs in Eastern Slope canyons as moraines apparently distinguishable both from Tioga and from Tahoe deposits; (4) Group III moraine sets record minor advances, probably since Climatic Optimum.

GEOLOGY OF THE MARMOLATA GROUP, SOUTH TYROL

C. James Blom
1050 Fell Street, San Francisco, Calif.

Investigations in the Dolomites, Northern Italy, were furthered under the direction of Professors Klebelsberg and Sander at the University of Innsbruck, Austria.

A bedded lower Triassic marine section is overlain by a 1000-m thick limestone "heap", like a bioherm. In this structure's center are originally horizontal thin (1 to 10 cm) beds, and sloping away (<30°) are 10 m beds of once para-indurated, resedimented conglomerates. Volcanic intrusive activity under the deeply submerged flank of this organic-poor bioherm (?) resulted in the expulsion of three great, partially shattered masses (100 to 1000 m wide) of the underlying sediments which spread upon the ocean bottom presumably as density flows. Blocks of the sedimentary rock 300 m long are thus suspended in brecciated volcanic material. Stratified tuff-conglomerate covered the bioherm (?) by late mid-Triassic.

Dolomitization of original limestone progressed inhomogeneously with formation of small (0.01 to 1 mm) dolomite rhombohedrons. An outcrop of a sharply defined "dolomitization front" was traced several meters. Sediment–introduced-tuff relations prove: (1) dolomitization occurred in completely indurated limestone, (2) enclosing tuff prevents dolomitization, and (3) Mendel dolomite here was limestone from Anis to at least mid-Ladin before becoming dolomitized.

Four vertical fracture systems are developed. Perpendiculars to the symmetry planes of the deformed sedimentary section define two horizontal B axes, E-W and N.65°–70°E. (both well known in the Austrian Alps). Seemingly, both were produced in one geologic period by alternating force concentrations.

The fractures, B axes, and rock character closely dictate the morphology, providing an excellent example of Gefuegerelief (Sander).

STRUCTURAL PETROLOGY OF THE PICO ANTICLINE, LOS ANGELES COUNTY, CALIFORNIA

Lawrence C. Bonham
California Research Corporation, P. O. Box 446, La Habra, Calif.

A petrofabric field and laboratory study was made of the rocks of the Pico anticline, Los Angeles County, California, to investigate the correlation between microstructures and large-scale structures and to determine the possibility of predicting large-scale structures from microstructures in unmetamorphosed sediments.

The Pico anticline is a flexure-slip fold in relatively poorly indurated conglomerates, sands, and shales of Upper Miocene and Pliocene age. Separate *B* axes are associated with the anticlinal axis, with the plunge axis, and with a change in strike of the fold.

The quartz in the sandstones shows both preferred dimensional and crystallographic orientation, but the evidence suggests that these are inherited depositional fabrics, rather than the result of deformation accompanying folding.

The quartz microfracture orientation shows a good correlation with the large structure in this area. The microfractures are preferentially oriented in the *ac* plane of the fold or in two sets bisected by the *ac* plane. The strike of the anticlinal axis can be determined within 20° from about 80 per cent of the oriented samples studied. The direction and amount of plunge of the fold can be determined with about equal accuracy.

This study provides evidence that, even in poorly indurated and relatively slightly deformed rocks, the microfabric can be correlated with the gross structure.

ECONOMIC ASPECTS OF THE ENGINEERING GEOLOGY OF SAN FRANCISCO, CALIFORNIA

M. B. Bonilla
U. S. Geological Survey, 4 Homewood Place, Menlo Park, Calif.

San Francisco's geology affects the costs of exploration, design, construction, and maintenance of structures.

The complex lithology and structure of the Franciscan group and the presence of faults and shear zones make prediction of subsurface conditions difficult, cause high exploration costs, and often result in large safety margins in contractors' bids and unexpected difficulties during construction. In contrast to the variable nature of the Franciscan group, the dune sand that underlies a large part of the city is quite uniform; design and construction involving this material is almost free of unknown factors. Another extensive deposit, a slightly cemented sand, is also comparatively uniform and, although easily excavated, seldom needs temporary support in excavations.

Landslides, mainly of the earth-flow type, are a continuing problem in San Francisco. Most of the slides are in older alluvium, but many are in weathered sandstone of the Franciscan group. Slides in serpentine are comparatively infrequent. Damage from the slides varies from only a small maintenance problem to destruction of houses or curtailment of the use of certain streets for years.

Like other cities in seismically active areas, San Francisco has extra costs resulting from earthquakes and potential earthquakes. Direct costs from earthquake damage are quite infrequent, but the costs of earthquake insurance and of constructing earthquake-resistant buildings are always present.

MECHANISM OF SALINA SALT DEPOSITION IN THE MICHIGAN BASIN

Louis I. Briggs, Jr. and Peter T. Lucas
Department of Geology, University of Michigan, Ann Arbor, Mich.

A comparison of the texture and mineralogy of a 5-foot core of the Silurian Salina salt from west-central Michigan with Usiglio's data on the chemistry of sea-water evaporation indicates that the salt was deposited in annual cyclic layers. Each layer of salt is characterized by halite, averaging 20 mm thick, underlain by a thin lamina of anhydrite averaging 0.5 mm thick. In the basal part of the layer, anhydrite is intermixed with minor amounts of dolomite and traces of quartz, hematite, and magnesite; whereas the upper part is almost pure halite with traces of anhydrite. The halite is composed of hopper-shaped crystals with cubic overgrowths of clear halite. Inasmuch as the hoppers are identical with those grown in salt pans by evaporation of sea water, the textures and mineralogy in the salt core are probably unchanged since their original deposition. Thus it is reasonably certain that they reflect the environment of deposition during a part of Salina time.

The deposition of separate anhydrite and halite laminae probably resulted from periodic influxes of sea water. It there were no new influx of brine until deposition of the subsequent anhydrite-halite layer, approximately 115 cm of influx water must have evaporated to form both anhydrite and halite layers. Since 115 cm (45 inches) is a reasonable annual evaporation rate for arid or semiarid regions, the composite anhydrite-halite layers probably represent precipitation from annual influxes of normal sea water evaporated under static conditions without continuous reflux.

X-RAY IDENTIFICATION OF CHLORITE SPECIES

G. W. Brindley and F. H. Gillery
The Pennsylvania State University, State College, Pa.

Identification of chlorites by x-rays has advantages over other methods for fine-grained impure materials. Since all chlorites have the same general structural scheme, and particular species differ only chemically, it is essential to consider the finer details of the x-ray pattern in any attempt to identify species by x-ray data alone. The principal isomorphous replacements are Al for Si in tetrahedral positions and Fe, Al . . . for Mg in octahedral positions. Simplifying assumptions reduce the problem for most chlorites to the determination of (1) proportion of octahedral sites occupied by Fe, (2) proportion of tetrahedral sites occupied by Al; *i.e.*, two parameters are involved, and these can be determined by consideration of (1) intensities of basal reflections, (2) basal spacing. The use of the b lattice parameter is considered inadvisable. Examples are given of the identification of three chlorites by the x-ray method prior to chemical analysis. Subsequent chemical analysis showed the x-ray data had given a reasonably accurate estimate of their compositions. While most chlorites are trioctahedral minerals, dioctahedral types and mixed di-tri types may exist. Their recognition from x-ray data is considered. Some precautions necessary when measuring and interpreting basal intensities with a counter spectrometer are discussed.

CARBON 14 AGE RESEARCH

Wallace Broecker and J. Laurence Kulp
Lamont Geological Observatory (Columbia University), Palisades, New York

Recent developments at the Lamont Observatory have involved extension of the C^{14} age method to 45,000 years by the utilization of large volume acetylene proportional counters with consequent increase in precision for modern samples. New measurements of geological and archeological samples supply information on a number of current problems. The rate of rise in sea level in the Mississippi Delta region over the past 30,000–40,000 years was studied by the aid of wood and shell material taken from cores. The rate appears to be about a foot per century. Both the Robson and Malaspina glaciers show evidence of advance followed by retreat during the past 500 years. Samples of peat from the James Bay area, Canada, suggest that the end of the continental glacier in that area occurred only some 3,000 years ago.

Fossil organic muck appears to give reliable ages which agree with wood in the same horizon. The first dates from the Neolithic archeological sites in southeastern China (Hongkong area) indicate 3,000 years. The alleged Norse ship at Follins Pond, Mass., is found to be from the Colonial period. A layer of dirt several feet from the surface of one of the ice islands shows an apparent age of less than 500 years, indicating relatively rapid accumulation. A "sea biscuit" from the top of the Atlantic seamount shows an age of 12,000 years. These and other results will be interpreted in terms of their geological significance.

REGIONAL DEVONIAN STRATIGRAPHY IN THE NORTHEAST PART OF THE GREAT BASIN

James E. Brooks
Department of Geology, Southern Methodist University, Dallas, Texas

Regional stratigraphic studies demonstrate that the Devonian Sequence (the stratigraphic succession above the Silurian Laketown dolomite and correlatives and below the Mississippian Madison limestone and correlatives) in central and western Utah and eastern Nevada is composed of three lithically distinctive stratigraphic intervals. They are, in descending order:

Interval	*Constituent Formations*	*Areal Extent and Typical Lithology*
Three Forks	Three Forks fm., Pilot sh., Mowitza sh., Devils Gate fm. (part), Pinyon Peak ls. and Victoria fm.	Distributed throughout area. Calcareous shales in miogeosyncline. Locally dolomitized limestones with sand and shale at base on stable shelf.
Jefferson	Jefferson fm., Red Warrior ls. (part), Devils Gate fm. (part), Simonson dol. & Guilmette fm.	Restricted to miogeosyncline. Limestones and secondary dolomites.
Sevy	Sevy dol., Water Canyon fm., Nevada ls. (part), Lone Mountain fm. (part)	Restricted to miogeosyncline. Primary dolomites, western Utah and eastern Nevada. Becomes sandier and shalier in northeast Utah and central Nevada.

Distribution of lithologies and thicknesses indicates the former existence of a miogeosyncline in the western and northern parts of the area and of an adjacent stable shelf in central Utah. Within the miogeosyncline the following subsidiary tectonic elements are recognized: (1) the Confusion Basin in west-central Utah; (2) the Central Utah Positive Axis which extends northwest from the vicinity of Salt Lake City; (3) the Northeastern Utah Embayment in the vicinity of Logan, Utah; (4) the Central Nevada Basin (only partially delimited by this study) in the vicinity of Eureka, Nevada.

GEOLOGY OF BARE MOUNTAIN, NYE COUNTY, NEVADA

Alfred L. Brown
P. O. Box 661, Tulsa, Okla.

On Bare Mountain, near Beatty, Nevada, latest Precambrian to Mississippian sedimentary rocks are exposed. The Cambrian units recognized are: Prospect Mountain, Pioche, Lyndon, Chisholm, Peasley, Burrows, an unnamed unit, Swazie, Highland Peak, and Nopah. The Ordovician includes the Pogonip, Eureka, and Ely Springs formations. The Silurian is represented by the Lone Mountain. Owing to faulting, most of the Devonian series is not exposed. Mississippian rocks include bedded cherts, tuffaceous silts, conglomerates, and black shales which are correlated with the White Pine shale of east-central Nevada.

Structural relationships are complex. Two distinct phases of thrusting are indicated. The earlier phase involves Palezoic rocks and is characterized by imbrication, overturning, and large displacement. Locally a chaos similar to that in Death Valley is developed. The thrusts are gently arched over Bare Mountain and serve as datum surfaces to delineate its post-thrust anticlinal structure. The later phase of thrusting involves relatively undisburbed Tertiary pyroclastics thrust upon the Paleozoic rocks.

North-south components of yield are indicated by the earlier structures in Bare Mountain. The substantiating evidence is: (1) the northward overturning, and (2) the nearly east-west trend of folds.

North-south, high-angle, normal faults sliced the range in the late Cenozoic. With few minor exceptions the relative displacement progressively drops the individual blocks to the east. Tectonic evidence in Bare Mountain suggests regional absolute downward movement.

LOWER CRETACEOUS AGE OF THE AMOLE ARKOSE, TUCSON MOUNTAINS, ARIZONA

Donald L. Bryant and John E. Kinnison
University of Arizona, Tucson, Ariz.

In 1938 W. Horatio Brown named a thick (3500 feet) sequence of nonmarine siltstone, sandstone, limestone, and arkose in the Tucson Mountains the Amole arkose and Recreation red beds. Probable equivalents of these two generally unfossiliferous units are widespread throughout southern Arizona, with thicknesses up to 15,000 feet or more. Stoyanow tentatively assigned these to the Upper Cretaceous Series on the basis of some *Mactra* found in the Amole arkose. Later Reeside examined a collection of fresh-water mollusks from another zone and stated that they were probably of Lower Cretaceous age. Recently the junior author discovered a zone of well-preserved, silicified ostracodes near the middle of the Amole arkose. Raymond E. Peck and one of his students at the University of Missouri, Richard Hoare, studied the fauna and determined that the great majority are *Metacypris pahasapensis* and *M. whitei*, very common forms in the nonmarine Jurassic and Lower Cretaceous of the Rocky Mountain region, but unknown in Upper Cretaceous rocks. Thus, some of these thick, nonmarine rocks assigned to the Amole arkose and the underlying Recreation red beds are most probably Lower Cretaceous and are not wholly Upper Cretaceous as they are now designated on the Correlation Chart of the Cretaceous Rocks of the Western Interior. They and their equivalents, in part at least, are contemporaneous with the rocks of the marine Bisbee group.

GROUPS, A NEGLECTED FACTOR IN EVOLUTION

Lancaster D. Burling
P. O. Box 3093, San Diego 3, Calif.

This preface to a 34-year study suggests group psychology and physiology as a potent factor in an evolution for which paleontology has ever discovered the quanta of species rather than chance mu-

tants. Pertinent grouping is further established by such phenomena as: termitaries in which the queen's presence is mandatory only if young and eggs are to be preserved; grouping in horses which makes possible the hypnotism of every member of the group by hypnotizing one; social-insect queens with an enlarged cephalic lobe during colony establishment, and an enlarged sympathetic head ganglion when she is apparently only an egg-layer; firefly groups which flash in unison despite partial isolation and disconcertment; herd grouping with a night sentinel each, which awakens a never-declining successor; social insects in which there is maintenance and control of caste quotas.

Explainable now are such phenomena as instinct and instincts; homing, especially where return is to other members of a group rather than to particular dovecots; migration where, for example, the young migrate before their parents; mimicry, notably where rapidity of consummation and intricacy of behavior and physiology are involved; mutation by methods other than those of chance or even of accidental simultaneity; death as other than an almost cosmic failure to conserve experience, operating within a scheme which makes survival to successful parenthood unessential; and an evolution by groups in which organizing higher-dimensional noumena are within the domain of pure science.

SUBSURFACE EXPLORATION BY THREE-DIMENSIONAL COLOR PHOTOGRAPHY

E. B. Burwell, Jr. and R. H. Nesbitt
Office of The Chief of Army Engineers, Washington, D. C.

Serious foundation problems in the construction of large concrete and earth dams have resulted from the frequent ineffectiveness of conventional 2⅛-inch core borings in disclosing such bedrock imperfections as weathered or open bedding planes, localized shear zones, and minor, though important, faults. Failure to detect such features prior to construction has resulted in extensive and costly modifications.

Prior to December 1952, the conventional procedure for reducing the chances of overlooking foundation imprefections was to resort to shafts, tunnels, and 36-inch calyx borings, which permit the engineering geologist to examine the foundation rocks in place. Such explorations are so costly as to greatly limit the extent to which they may be used on any one project.

To take full advantage of the most economical exploratory tool available to engineers and geologists, the small-diameter core hole, the Corps of Engineers have perfected a camera which will take continuous 360-degree color photographs of the interior surface of such borings. The camera has demonstrated conclusively the value of three-dimensional color photographs of borings in field tests on five large dam projects and has revealed many important subsurface conditions not disclosed by core samples.

The paper is supplemented by a demonstration of the camera and projection equipment, and the showing of representative field results in color pictures.

ESTIMATION OF RESERVES FOR URANIUM-VANADIUM DEPOSITS ON THE COLORADO PLATEAU

A. L. Bush and H. K. Stager
U. S. Geological Survey, Grand Junction, Colo.

Because of their variance in grade, size, and shape, carnotite deposits of the Colorado Plateau present special problems when estimating reserves. To obtain comparable results from various appraisers, the U. S. Geological Survey has adopted basic assumptions and standardized rules for calculating reserves.

Deposits are generally considered as tabular masses. Projections between and beyond sample points are governed by geologic reasoning. A bimetal grade scale is used because of the intimate

association of uranium and vanadium and the marketability of both minerals. Mineralized material that does not meet strict cutoffs in both grade and thickness is excluded from the reserves.

To determine the accuracy of the original reserve estimates and their significance in terms of total reserves, a reappraisal was made of 30 representative deposits after they had been developed by mining. Original estimates for some individual deposits were far too high, in both tonnage and grade, and others were much too low. For the total of deposits reappraised, however, the original estimates were only slightly low in tonnage and V_2O_5 grade, and the U_3O_8 grade had been estimated accurately.

HISTORICAL SKETCH OF ENGINEERING GEOLOGY IN SOUTHERN CALIFORNIA

John P. Buwalda
California Institute of Technology, Pasadena, Calif.

Before 1925 geological knowledge was applied to engineering projects in southern California only in sporadic cases. While the St. Francis dam disaster in 1928 unquestionably hastened recognition of its need, the growth of engineering geology apparently resulted principally from two general developments: rapid increase of comprehension by engineers and public of the nature of geologic science, and final realization by engineers and geologists that adjacent parts of a site are essentially parts of an engineering structure and must possess comparative strength. Widened appreciation of engineering geology is illustrated by the two great aqueduct projects. Very limited geologic study was given to the original Owens Valley aqueduct (about 1910–1915), but geology played an important role in planning and construction of the Colorado River aqueduct (about 1930–1935) through influence on choice of route among many alternates, avoidance of underground crossing of active faults, prediction of geological conditions and of underground water relations in alternate proposed tunnels, geological exploration of many dam sites along the aqueduct, and search for readily accessible construction materials. In planning dams geological advice was only occasionally sought in 1900–1925, and geological examinations made were often rather superficial; since about 1929 thorough geological exploration of all dam sites has been compulsory under state law. During the last quarter century engineering geology applications have increased enormously in southern California in connection with dams, tunnels, open cuts, foundations, landslides, active faults, seismic stability of ground, coastal projects, land subsidence, construction materials, and ground water sources.

CORRELATIVE UNITS IN THE SAN RAFAEL GROUP ON THE COLORADO PLATEAU

R. A. Cadigan
U. S. Geological Survey, Grand Junction, Colo.

Correlation of units within the San Rafael group (Jurassic) in the Colorado Plateau region is complicated by alternating lateral changes in lithologic facies that have resulted in the application of a legitimate but confusing number of unit names to similar facies in the same stratigraphic interval.

As a solution to the regional correlation problem, a scheme is proposed for dividing the San Rafael group into three parts, each of which has a high degree of regional continuity and each of which contains rocks interpreted as having been deposited under environments closely associated in both time and space. From top to bottom these are:

(1) The Entrada sandstone and the related Carmel formation

(2) The Todilto limestone, the correlative Pony Express limestone member, and the overlying closely related Bilk Creek sandstone member of the Wanakah formation

(3) The intertonguing mutually equivalent red, green, and brown siltstone units (such as the Curtis, Summerville, and the siltstone member of the Wanakah formation) and the more than 100-foot-thick massive sandstone units (such as the Moab member, and the Bluff and Junction Creek sandstones) and their thinner sandstone equivalents.

These three divisions of the San Rafael group may be correlated over the Plateaus region as reliably as are the overlying Morrison formation and underlying Glen Canyon group.

RELATIONSHIP BETWEEN DENSITY AND COMPOSITION IN THE COLUMBITE-TANTALITE SERIES

William J. Campbell and John G. Parker
U. S. Bureau of Mines, College Park, Md.

A study was undertaken to determine if the Nb_2O_5/Ta_2O_5 ratio in members of the columbite-tantalite series could be evaluated from the relationship of density to composition.

A number of samples in this series were analyzed by fluorescent x-ray spectrography. The samples were checked by x-ray diffraction on a wide-range goniometer. Densities were measured with a precision of ± 0.02 by application of a double pycnometer technique.

The theoretical relationship between density and Nb_2O_5/Ta_2O_5 ratio indicates that density is a linear function of the atomic per cent Ta_2O_5. The x-ray diffraction studies show a small decrease in unit-cell size with increasing FeO/MnO ratio but independent of the Nb_2O_5/Ta_2O_5 ratio. The following equation was obtained:

$$\rho = (A + B \text{ atomic } \% \ Ta_2O_5)(1 + C \text{ atomic } \% \ FeO)$$

in which A, B, and C are empirically determined constants.

Application of the above expression permits evaluation of the Nb_2O_5/Ta_2O_5 ratio with an accuracy equal to that obtained by conventional chemical techniques.

CONTEMPORANEOUS SLUMPING AND SLIDING IN THE BANDED GABBROS OF THE ISLE OF SKYE, SCOTLAND

J. M. Carr
% Department of Geology, University of Illinois, Urbana, Ill.

Structures attributed to slumping and sliding of stratified crystal mush occasionally affect gabbroic rocks at the heart of the Cuillin complex. The rocks are at differing horizons of a Skaergaard-type layered series that formed by the bottom accumulation of discrete crystals on inclined surfaces. The observed dip of undisturbed layers ranges between 35° and 50°. Blocky xenoliths of layered gabbro have been emplaced by gravity sliding over the sloping surface of the parent layer, in places with the formation of a slide breccia. Lack of disturbance in overlying layers indicates sliding while the host layer was still accumulating. Fracturing and separation of blocks was generally confined to layers possessing an igneous lamination. Accompanying massive-textured layers, formed of more liquid mush, have flowed rather than fractured. The variable fluidity of the interlayered mush seems to explain earlier erroneous views on the age relations of the Cuillin banded gabbros.

EFFECT OF GRAIN SIZE ON THE EFFICIENCY OF MODAL ANALYSIS OF GRANITIC ROCKS

F. Chayes
Geophysical Laboratory, 2801 Upton St., N.W., Washington, D. C.

A measurement area sufficient to include a very large number of grain sections of a fine-grained rock may contain relatively few grain sections of a coarse-grained rock; it thus provides a highly efficient sample of the former and a poor sample of the latter. The strength of this effect has been examined on three granite specimens of widely differing grain size.

Analyses were run with fixed count length on measurement areas of *ca* ¼, ½, ¾ and 1½ in² on 10 sections of each specimen. For the fine-grained rock (Westerly) the smallest measurement area is not significantly less efficient than the largest. For the medium-grained rock (Mt. Desert) dispersion decreases materially with increase of measurement area, and an area of 1½ in²—about as large as can be analyzed in a single setting on standard equipment—provides a sample adequate for most purposes. Decrease of dispersion with increase of measurement area is more extreme in the coarse-grained speciman (Carnmenellis) but even at the largest measurement area scatter is still so large that a single thin section per hand specimen can yield little information about variation within the rock mass.

The number of grain sections per unit area may provide a usable index of efficiency. Preliminary counts indicate, for instance, that an area of 1 in² probably contains more than 7000 grain sections of the Westerly specimen but less than 700 of the Carnmenellis specimen.

MATTERHORN PEAK QUADRANGLE, EASTERN CALIFORNIA

Charles W. Chesterman
California State Division of Mines, Ferry Bldg., San Francisco 11, Calif.

The Matterhorn Peak quadrangle, on the crest of the Sierra Nevada in eastern California, comprises the southwest quarter of the U. S. Geological Survey Bridgeport quadrangle and includes parts of Mono and Tuolumne counties and part of Bridgeport Valley.

The oldest rocks in the quadrangle are steeply dipping metalimestones, metacherts, quartzites, and hornfelses of Paleozoic (?) age unconformably overlain by equally steeping dipping metavolcanics of Triassic age. The metavolcanics include flows, tuffs, agglomerates, and breccias of rhyolite, dacite, andesite, and basalt; meta-andesites predominate. This complex of metamorphic rocks was intruded by a complex of Jurassic igneous rocks including granites, quartz diorites, quartz monzonites, gabbros, and serpentine.

More or less horizontally upon the basement rocks are Mio-Pliocene volcanic rocks, Pleistocene moraines, and recent sediments.

The metamorphism of the basement metasediments and metavolcanics was due to a mixture of thermal-, dynamo-, and metasomatic processes, much of which probably took place prior to the emplacement of the Jurassic granitic rocks. Base-metal mineralization in the metalimestones is believed to have accompanied intrusion of the Jurassic granitic rocks.

Bridgeport Valley is in part a structural depression bordered on the west and northwest by faults of considerable displacement.

Economic mineral resources are few. Gold has been mined from quartz veins in the granitic and metavolcanic rocks, and gravel for road construction has been obtained from bouldery glacial deposits. Copper, lead, zinc, and tungsten mineralization occur in the metamorphosed limy sediments.

PRECISION DETERMINATION OF LATTICE CONSTANTS OF SINGLE CRYSTALS USING THE CONVENTIONAL WEISSENBERG CAMERA

C. L. Christ
U. S. Geological Survey, Washington, D. C.

The well-known graphical extrapolation method of Bradley and Jay [Proc. Phys. Soc. *44*, 563 (1932)] is a very powerful means of obtaining precise lattice constants of crystals. However, to apply this method the spacing data derived from film measurements must be relatively free from errors due to film shrinkage and incomplete knowledge of the camera radius. In the present method a powder pattern of finely divided, annealed silver is recorded on the Weissenberg pattern of the crystal under study. From measurements of the silver pattern a film constant as a function of 2θ is derived. This is used to convert linear measurements of the Weissenberg spots to the corresponding 2θ values. With a conventional Weissenberg camera and a relatively crude commercial measuring device a precision of lattice constant of 3 to 4 parts in 10,000 may be obtained routinely from a single crystal.

CRYSTAL STRUCTURE OF COLEMANITE, $CaB_3O_4(OH)_3 \cdot H_2O$

C. L. Christ, Joan R. Clark, and H. T. Evans, Jr.
U. S. Geological Survey, Washington, D. C.

Colemanite is monoclinic $P2_1/a$, $a = 8.743 \pm 0.004$, $b = 11.264 \pm 0.002$, $c = 6.102 \pm 0.003$ A, $\beta = 110°07' \pm 05'$, $Z = 4$ [Christ, Am. Mineral. *38*, 411 (1953)].

From extensive three-dimensional intensity data the phases of 944 observed structure amplitudes were calculated by the method of Hauptman and Karle (ACA Monograph #3, The Letter Press, Wilmington, Del., 1953). These results were used to calculate electron-density sections over the xz plane at intervals along y of $1/60$, for from $y = 0$ to $y = 1/4$. Analysis of the electron-density sections shows that infinite boron-oxygen chains parallel the a axis. The chain element has the composition $[B_3O_4(OH)_3]^{-3}$ and consists of a BO_3 triangle and two BO_4 tetrahedra. The average B—O bond length in the tetrahedra is 1.4_3 and in the triangle is 1.3_7 A. Ca^{++} has as nearest neighbors five oxygens and one water molecule at an average distance of 2.4_4 A.

APPLICATION OF ELECTRON DIFFRACTION TO THE STUDY OF METAMICT MINERALS

C. L. Christ, E. J. Dwornik, and M. S. Tischler
U. S. Geological Survey, Washington, D. C.

Metamict minerals, whose structures have been distorted by bombardment by the emanations from radioactive elements, yield poor or no x-ray-diffraction patterns and optically are birefringent or isotropic. At least some of these metamict minerals give sharp electron-diffraction patterns. Apparently, sufficient relict crystallinity is retained so that the relatively short wave-length electrons ($\lambda = 0.055$ A at 50 KV) will yield resolved patterns.

Electron-diffraction studies have been started on various metamict minerals. Zoned zircon from Oklahoma was examined, and both fresh and highly metamict portions of a given zircon yielded numerous diffraction rings. X-ray diffraction patterns of these same samples were sharp and with measurable lines in the case of fresh zircon, but they were poor and with no measurable lines in the case of the metamict zircon. Similarly, good electron-diffraction patterns of metamict samarskite and polycrase have been obtained.

GEOMORPHIC CLASSIFICATION OF DESERT TYPES

Thomas Clements
Department of Geology, University of Southern California, Los Angeles, Calif.

A geomorphic classification of types of desert topography has been developed as the result of several years' work by the author and his colleagues in the hot, dry area of southwestern United States. These types are distinctive and can be recognized in other hot deserts of the world and probably in the warm deserts as well. The classification is as follows:

(1) Playas: the flat or nearly flat low part of an enclosed basin. Playas can be subdivided into (a) dry, (b) moist, (c) crystal body, (d) compound, and (e) lime-pan

(2) Desert Flats: the essentially flat surfaces extending from the edges of the playa to the alluvial fans or the bajadas

(3) Alluvial Fans: the fan- or cone-shaped deposits at the mouths of canyons

(4) Bajadas: alluvial aprons resulting from the coalescing of alluvial fans

(5) Bedrock Surfaces: results of erosion, and subdivided into (a) pediments, (b) desert domes, and (c) hammadas

(6) Dry Washes: stream-formed, but occupied by streams only at rare intervals

(7) Dunes: accumulations of wind-blown sand

(8) Badlands: soft deposits of any type eroded into rugged topography by sudden, heavy, but infrequent rains

(9) Regions Bordering Through-flowing Streams: desert areas traversed by rivers rising in humid regions

(10) Desert Volcanics: Recent or Pleistocene volcanics occurring commonly in desert areas, although not genetically related to the desert

(11) Desert Mountains: mountains separating or bordering desert basins

OPTICAL AND CHEMICAL STUDY OF JADEITE FROM CALIFORNIA

Robert G. Coleman
U. S. Geological Survey, Washington, D. C.

The green to white jadeite from Clear Creek, San Benito County, California, described by Chesterman and Yoder has been further investigated as part of a mineralogic and petrologic study of the New Idria district. The jadeite is found in small veins cutting albite-glaucophane-acmite schist and as larger lens-shaped pods within serpentine. The vein jadeite is associated with albite, analcite, natrolite, and thomsonite. Prehnite, hydrogrossular, thomsonite, and minor sphene are found associated with the jadeite pods. A chemical analysis, in per cent, shows the white vein material to be almost pure jadeite: SiO_2 59.38, Al_2O_3 25.82, FeO traces, Fe_2O_3 0.45, TiO_2 0.04, MnO nil, CaO 0.13, MgO 0.12, K_2O 0.02, Na_2O 13.40, H_2O+ 0.22, H_2O- 0.16, Cr_2O_3 0.01, total 99.75. Optical data: $\alpha = 1.654$, $\beta = 1.657$, $\gamma = 1.666$, $\gamma - \alpha = 0.012$, $2V = 70° \pm$, $Z \wedge c = 34°$, $X = Z = Y$ colorless. Density: 3.43 ± 0.01. Chemical analysis of the green jadeite shows that it carries about 10 per cent of the diopside molecule and 14 per cent of the acmite molecule. The mineral association suggests that the jadeite has formed under low temperature and pressure conditions, and that there are several possible modes of origin.

LATE PLEISTOCENE AGE OF THE SNAKE RIVER DIVERSION

Earl F. Cook and Earl J. Larrison
University of Idaho, Moscow, Idaho

The diversion of the Snake River, from a course which may have taken it into California, by the spilling over of an arm of Lake Idaho into a northward-flowing tributary of the Salmon River probably took place in the latter half of the Pleistocene. High-level outwash gravel at several localities in southwest Idaho and eastern Oregon occurs near the probable maximum surface elevation of Lake Idaho; this gravel, fairly well consolidated and slightly weathered, probably records a late Pleistocene, pre-Wisconsin glacial age, during which the spillover occurred.

Faunal evidence also supports the late Pleistocene age of the diversion. The mammal fauna of the Seven Devils Mountains in Idaho is largely identical with and at most only subspecifically different from that of the Wallowa Mountains across Hells Canyon, which is today an insurmountable barrier to most of the smaller animals. It is estimated that the genetic drift shown on opposite sides of the canyon represents not more than 200,000 years; before that, the Hells Canyon barrier did not exist. On the other hand, the fauna of the Owyhee desert in southwest Idaho south of the Snake is different, except for a few newly arrived species, from the eastern Oregon fauna; as there is today no barrier to migration to this area, the evidence supports the hypothesis that the Snake River before diversion flowed southwest toward California.

BURIED CHANNELS AT NORTHWEST CITIES DAM SITES

Howard A. Coombs
University of Washington, Seattle, Wash.

The cities of Seattle, Tacoma, and Eugene are investigating dam sites where buried channels exist containing a great variety in the type of fill material. Some channels are filled with glacial drift and outwash as at Tacoma's site on the South Fork of the Skokomish River in the Olympic Mountains, or Seattle's site on the South Fork of the Tolt River in the Cascade Mountains.

In contrast, the fill at Seattle's Gorge site on the Skagit River is composed of huge blocks, up to the size of a house, that have fallen from the vertical canyon walls and buried two channels to a depth of 200 feet. A few miles downstream on the Skagit River at another possible dam site the former river bed is covered by a slump from one side and a huge landslide on the opposite side of the river. Again the blocks of bedrock in the slide are as large as a house. The random orientation of lineation and schistosity in the blocks proves they are moved rocks and not knobs of bedrock.

On the Upper McKenzie River in Oregon, Eugene is investigating a site in which very porous blocky lava of the aa type has partially filled a previously covered deep valley in andesites and basalts. For part of its course the river runs underground through this porous fill.

OLDER PRECAMBRIAN ROCKS OF THE DRAGOON QUADRANGLE, COCHISE COUNTY, ARIZONA

John R. Cooper and Leon T. Silver
U. S. Geological Survey, Denver Federal Center, Denver, Colo.; U. S. Geological Survey and California Institute of Technology, Pasadena, Calif.

The older Precambrian rocks of the Little Dragoon Mountains and the Johnny Lyon Hills comprise strongly deformed Pinal schist and intrusive rhyolitic porphyry and large bodies of post-deformational granodiorite and granite. The Pinal schist consists of 9000 to about 20,000 feet of metamorphosed graywacke, subgraywacke, slate, conglomerate, tuff(?), silicic extrusives, and basalt with associated jasper beds. The structure is a complex of isoclinal folds, which trend northeast and commonly have steeply overturned limbs and axes. Laramide thrusting has modified the Precambrian structure. The metamorphic rocks range from low-grade green schist facies, which possess much of the original lithologic character, to amphibolite facies, in which dynamic effects have commonly produced strong boudinage structure. Retrogressive metamorphic effects are widespread. The Pinal schist is interpreted as a eugeosynclinal accumulation of sedimentary and volcanic rocks. Most of the Pinal and Yavapai schists of southern and central Arizona probably originated in a major geosynclinal trough whose complete extent is not yet known. This trough was the orogenic site of Wilson's Mazatzal revolution.

NATIVE COPPER DEPOSITS

H. R. Cornwall and W. S. White
U. S. Geological Survey, Washington 25, D. C.

Native copper occurs in mafic lavas, hypabyssal diabasic intrusives, ultramafic intrusives, clastic sedimentary rocks, and the oxidized zone of sulfide deposits. Native copper predominates over sulfide copper in mafic lava flows—best exemplified in the Lake Superior region—and in some sedimentary rocks, but is typically subordinate to sulfide copper elsewhere.

Possible origins of native copper include: precipitation from sulfide-bearing hydrothermal solutions in rocks containing ferric oxide; deposition from sulfur-deficient hydrothermal solutions; deposition from meteoric or hydrothermal chloride solutions in the presence of calcite, prehnite, or zeolites;

precipitation from hydrothermal solutions by ferrous salts; organic precipitation from meteoric waters; reduction of copper sulfides by meteoric waters in the zone of oxidation; reduction of primary copper sulfides by later hydrothermal solutions.

Traces of native copper in mafic lava are believed to have crystallized as the lava cooled. The native state of the copper is attributed to escape of sulfur in gases during extrusion. Later concentration of this native copper by hydrothermal solutions may form economic deposits. The hot water that formed the Lake Superior deposits need not have been magmatic in origin, but may well have been water buried with the lava and driven up the dip of the flows by heat and pressure in the depths of the Lake Superior basin. More highly metamorphosed lavas with native copper, like the Catoctin greenstone of the Appalachians, the Triassic lavas of Oregon, and lava of Copper River, Alaska, presumably resemble rocks down the dip from the Michigan copper deposits.

ISOTOPIC GEOCHEMISTRY OF THERMAL WATERS

Harmon Craig, Giovanni Boato, and Donald E. White
Institute for Nuclear Studies, University of Chicago, Chicago, Ill.; Institute for Nuclear Studies, University of Chicago, Chicago, Ill.; U. S. Geological Survey, Menlo Park, Calif.

The relationships between volcanic and hot-spring waters and local meteoric waters are being studied by "natural" isotopic tracer techniques utilizing both deuterium and oxygen 18. The isotopic "labelling" is provided by multiple-stage fractional-distillation processes over the oceans which produce large variations in the isotopic composition of meteoric waters in different regions of the earth. Thermal waters in areas of widely different surface-water composition are then studied in detail for seasonal variations in isotopic and chemical composition.

The lightest thermal waters so far encountered occur at Yellowstone Park, while the heaviest occur in New Zealand; these differences are matched by the meteoric waters. The thermal waters in these localities differ in deuterium and oxygen 18 content by as much as 20 and 3 per cent, respectively, yet the isotopic relationships between surface waters, alkaline hot springs, and acid springs are the same in these and in areas of intermediate meteoric water composition. These relationships, correlated with experimental evidence, show that the acid hot springs in all areas examined are of secondary origin, derived from near-neutral and alkaline ground waters by nonequilibrium evaporation-condensation processes in which the waters become enriched in the heavy isotopes and in sulfuric acid. The alkaline springs are of direct meteoric origin; small amounts of juvenile or "recycled" water may be present, and detailed studies are being made on the maximum percentages of these constituents.

ALIGNED CURRENT STRUCTURES FROM THE PREALPINE ULTRAHELVETIC FLYSCH, SWITZERLAND

John C. Crowell
Department of Geology, University of California, Los Angeles, Calif.

Sandstone beds in the Paleocene-Eocene Flysch of the External Prealps, Switzerland, belonging to the Gurnigel sandstone and exposed near Schwarzenbuehl, Hoellbach, and La Mortivue, display primary current structures which exhibit common orientation through many feet of strata. These aligned structures include groove casts and load casts on the bottom of sandstone layers, streaks and lined-up charcoal fragments on bedding planes within layers, and rare ripple marks on tops of beds. Other oriented structures are: current bedding, convolute bedding, and some as yet unnamed. These and other factors suggest that the sediments were laid down by turbidity currents in a relatively sheltered marine basin.

In three sections of the Gurnigel Flysch, 403 field measurements of the orientation of current structures show that during the Paleocene and Eocene a source for sediment lay not far to the northwest. This information, combined with published data on clast types and the distribution and facies

of other Paleocene and Eocene units, implies that a landmass or island lay within the northwestern part of the Ultrahelvetic sedimentation region, within which the Gurnigel Flysch accumulated, and near the border of the Helvetic region. Oligocene and Pliocene culminations of the Alpine orogeny carried the Gurnigel Flysch far to the northwest within Ultrahelvetic nappes.

The study indicates that much can be learned about paleogeography and the region of sedimentation from the examination and measurement of oriented current structures. Such information in turn may aid in understanding the tectonic history of a complex region.

PLEISTOCENE GEOLOGY OF PLATTE COUNTY, MISSOURI*

Stanley N. Davis
Department of Geology, Stanford University, Calif.

Platte County, Missouri, borders Missouri River north of Kansas City and east of Leavenworth, Kansas. Loess caps all hills in Platte County and extends into valleys adjacent to the Missouri River flood plain. Till and associated gravel underlie the loess on hill crests but are generally absent in the valleys. Pennsylvanian limestones, sandstones, and shales crop out along the valley walls.

Evidence for tills of two ages is lacking in Platte County. The absence of sedimentation between the time that till was deposited and the time that overlying loess of Illinoian age was deposited suggests that the till is Kansan. If so, the Nebraskan till border is north of Platte County and is thus more than 30 miles north of the Nebraskan till border shown on the Glacial Map of North America.

Buried soils divide the loess into three units which are correlated with Loveland loess, Peorian loess, and Bignell loess. A small circle of cobbles with finely divided charcoal in the center and clam shells, flint chips, and bone fragments near by was found buried under 15 feet of Bignell loess a quarter of a mile north of Beverly, Missouri. This hearth site is a lowland position along a valley which is tributary to Missouri River and duplicates the geologic setting of the Lansing Man site 9 miles south of Beverly. The age of Lansing Man, which has been a subject of controversy for 52 years, is judged to be late Wisconsin.

GEOLOGY OF THE FREMONT PEAK AND OPAL MOUNTAIN QUADRANGLES, SAN BERNARDINO COUNTY, CALIFORNIA

T. W. Dibblee, Jr.
U. S. Geological Survey, Claremont, Calif.

The geology of about 480 square miles in the west-central Mojave desert was mapped on aerial photographs. The area includes Harper Valley, Fremont Peak, Opal Mountain, Black Mountain, and the Mud Hills.

The hills of the western, northern, and eastern portions of the mapped area are underlain by a complex of Jurassic(?) granitic intrusives, enclosing several pendants of Paleozoic(?) schists and limestones, and is locally cut by rhyolitic dikes. This complex is overlain unconformably by about 6000 feet of Tertiary strata which lie concealed under Harper Valley and are exposed throughout the hills adjacent north and east. The strata are composed of Miocene(?) volcanic, pyroclastic, and sedimentary rocks unconformably overlain by upper Miocene clastic sediments. Local extrusions of Pliocene(?) andesite and Pleistocene basalt lie unconformably on the Tertiary and pre-Tertiary rocks.

The southwestern half of the mapped area has been relatively stable during late Tertiary and Quaternary times, but the northeastern half was elevated and locally tilted on two zones of high-angle northwest-trending faults. The Tertiary strata between these two fault zones are compressed into east-trending folds. The overlying Pleistocene basalt sheet is severely buckled along each fault zone and tilted eastward away from each to form two broad sloping mesas.

Drainage within the mapped area in mid-Pleistocene time was probably all southward via Harper

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Valley to the Mojave River. This has been disrupted by subsequent uplifts on the major fault zones causing the development of undrained playas.

SYSTEMS HgS-Na_2S-H_2O AND HgS-Na_2S-Na_2O-H_2O

Frank W. Dickson and George Tunell
Department of Geology, University of California, Los Angeles, Calif.

Field evidence suggests that cinnabar and metacinnabar are deposited from sulfide solutions at temperatures ranging upwards from 100°C and at pressures of a few atmospheres. Since these conditions are attainable in the laboratory the authors have investigated the ternary system HgS-Na_2S-H_2O and the quaternary system HgS-Na_2S-Na_2O-H_2O. The saturation curves of cinnabar and metacinnabar in the ternary system HgS-Na_2S-H_2O, in the concentration range from 75 to 100 per cent water, have been determined at 25°C, 50°C, and 75°C. The saturation surface of cinnabar in the quaternary system HgS-Na_2S-Na_2O-H_2O in the concentration range from 75 to 100 per cent water has been determined at 25°C. Work now in progress includes determining saturation surfaces in the quaternary system at higher temperatures and a study of the quinary system HgS-Na_2S-Na_2O-SiO_2-H_2O.

Saturated solutions were analyzed for mercury, sulfur, and sodium; water percentages were obtained by difference. Solid phases were identified by means of the x-ray spectrometer and petrographic microscope.

VERY LATE MIOCENE (LATE BARSTOVIAN) MAMMAL FAUNULE FROM THE MADISON VALLEY FORMATION, MONTANA

John A. Dorr, Jr.
Dept. of Geology, University of Michigan, Ann Arbor, Mich.

The eastern bluffs of the lower Madison River Valley south of Three Forks, Montana, are the type locality of the Madison Valley formation. At the northern end of the bluffs, the lowest exposed beds are the Miocene *Leuciscus turneri* lake beds. Above, to the top of the bluffs, is the Madison Valley formation, a fluviatile deposit with rare lacustrine lenses. From the bluffs, a dip slope declines eastward to the Gallatin River. Pleistocene gravels cap this surface locally, but it is largely underlain by the Madison Valley formation. Late Miocene mammals have been collected from exposures in the bluffs, but the localities and stratigraphic levels from which many came remain uncertain or are inexactly recorded. Carnegie Museum parties recently collected several closely associated mammals from a gray volcanic ash channel fill along the south side of the road between Bozeman and Anceney, 13 miles west of Bozeman (Center of N. ½, Sec. 13, T. 2 S., R. 3 E., Gallatin Co.). The faunule includes: *Mesogaulus*? cf. *M. ballensis*, *Monosaulax pansus*?, *Martes* sp., *Hypsoparia bozemanensis* Dorr, 1954, *Merychippus* (*Protohippus*) near *M. intermontanus*, and a camel resembling *Rakomylus*. The locality lies on the back slope southeast of the type locality of the Madison Valley formation. The exact stratigraphic level of the faunule within that formation could not be determined by lithologic continuity. However, lithologic similarity and approximation of the surface to a dip slope indicate that the fossil horizon correlates with beds exposed in the upper part, probably the upper quarter, of the river bluffs.

CHAETETES, IMPORTANT MARKER IN PENNSYLVANIAN OF CENTRAL GREAT BASIN*

Robert H. Dott, Jr.
Humble Oil & Refining Co., 751½ E. 16 Avenue, Eugene, Ore.

Of the Pennsylvanian in eastern Nevada and western Utah, Springeran-Morrowan cherty limestones (1000–1500 feet) are most widespread and best exposed but are monotonous and poorly di-

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visible. Higher rocks (Atokan and younger) contain fusulinids, which facilitate subdivision and correlation. The stratigraphic importance in this region of *Chaetetes* coral colonies in the upper part of the lower limestones has not heretofore been appreciated. Fine radiating corallite tubules form hemispherical masses up to 3 feet in diameter, generally silicified. Colonies are closely spaced in a zone less than 10 feet thick typically, but near Eureka, Nevada, occur in several beds through a thickness of 200 feet (possibly local biohermal development). The zone of abundant colonies is generally thin and very widespread, suggesting a biostrome. Other corals and lowest abundant fusulinids are closely associated. Short-ranging *Profusulinella*, fewer *Millerella*, rare primitive *Fusulinella*, and other Foraminifera suggest Atokan age. Because this association is so widespread and restricted in range, the *Chaetetes* faunizone appears to be a nearly synchronous time-stratigraphic marker. It is especially useful for field work and is commonly mappable; thus closer attention should be paid to the position of this most important Pennsylvanian marker. Evidence now suggests rather close correlation throughout the Cordilleran region, but identification of associated fusulinids is essential for confirmation. By contrast, *Chaetetes* has greater stratigraphic range in the mid-continent and is most abundant in Desmoinesian rocks.

CRYSTAL STRUCTURE OF SANBORNITE, $BaSi_2O_5$

Robert M. Douglass
University of California, Berkeley, Calif.

Sanbornite, previously described as triclinic, is apparently orthorhombic; space group *Pcmn*. The unit cell, $a = 4.63$, $b = 7.69$, $c = 13.53$ Å, contains $4BaSi_2O_5$.

A structure with 13 parameters has been found with the aid of Patterson and Fourier projections. It is a silicate sheet structure with two parallel, identical $Si_4O_{10}^{-4}$ sheets per unit cell lying in $x, y, \frac{1}{4}$ and $x, y, \frac{3}{4}$, and two Ba^{+2} lying roughly half way between each successive pair of sheets. Each $Si_4O_{10}^{-4}$ sheet may be regarded as made up of continuously linked, distorted six-membered rings of SiO_4 tetrahedra. The tetrahedra are arranged in pairs, one tetrahedron lying on either side of the *m* plane in $x, \frac{1}{4}, z$ or $x, \frac{3}{4}, z$. Pairs of tetrahedra within one sheet are related by glide reflection on the *n* plane in $x, y, \frac{1}{4}$ or $x, y, \frac{3}{4}$, so that unshared vertices of alternate pairs point up, the others down. Each sheet is derivable from the other by glide reflection on the *c* plane in $\frac{1}{4}, y, z$ or $\frac{3}{4}, y, z$. Each barium atom is surrounded by seven nearest oxygen atoms.

EARED SEALS OF THE FAMILY OTARIIDAE FROM THE MIOCENE OF THE PACIFIC COAST

Theodore Downs
Los Angeles County Museum, Exposition Park, Los Angeles, Calif.

Certain characters of the skeleton in known Miocene genera of Otariidae reveal "primitive" conditions as compared with later otariids. Evidence is based on the study of Miocene otariids from the Astoria formation of Oregon and formations in California including: the Santa Margarita, Santa Cruz County; the Temblor, Kern County; the "diatomaceous earth" (Monterey) near Lompoc, Santa Barbara County; the Valmonte and Altamira members of the Monterey Series of Los Angeles; and the Monterey in the San Joaquin Hills of Orange County.

Specimens from these formations are characterized by: mandible with straight angle, slender horizontal ramus; scapula with angular coracovertebral margin and wide anteroposterior diameter of neck; humerus with slight posterior curvature, general slimness of the shaft, reduced greater tuberosity, small head with slight angle relative to long axis of shaft and moderate deltoid crest; radius with straight shaft and rounded contour; ulna with slight posterior curvature and rounded shaft contour.

The attributes of the fore limb indicate probably less specialized adaptation for swimming than is true of late Pliocene, Pleistocene, and Recent otariids.

Evidence from the study of the morphology of these pinniped elements assists considerably (along with geologic and invertebrate paleontologic data) in interpreting geologic age of pinnipeds and their containing strata. This is true at an epoch and, to a lesser extent, at a stage or age level.

STRUCTURAL GEOLOGY OF THE SOUTHERN SNAKE RANGE, NEVADA

Harald Drewes
U. S. Geological Survey, General Geology Branch, Denver Federal Center, Denver, Colo.

There is at least 14,000 feet of Cambrian to Pennsylvanian(?) strata in the Wheeler Peak and Garrison quadrangles that straddle the southern Snake Range in eastern Nevada.

At least six thrust faults generally follow the shaly formations and in many places up to many thousand feet of strata is cut out. The upper thrust plates moved relatively east-northeast. A fence section and a structure contour map of one of these thrust faults show the coincidence of some of the structurally low belts in the thrust plane with areas of gouged-out underlying shaly beds. The sequence of truncation of the thrust plates indicates that successively higher plates were active as the underlying ones were essentially locked in place. Some normal faults in the widespread thrust breccia sheets are restricted to one or several thrust plates and are believed to be contemporaneous with the thrust faults. Only one major orogeny of probable Late Mesozoic or Early Tertiary age is necessary to explain these structures; very likely they are the near-surface expression of one major thrust zone.

Two Tertiary granitic stocks that show little contact alteration, a coincidence with regional and local structural domes, and drag features along their borders indicate that a viscous magma was forcibly injected at relatively low temperature.

Several periods of movement along high-angle faults bordering the range are recorded by major unconformities in the probable Late Tertiary to Recent deposits flanking the range, and by various erosion surfaces.

SILURIAN FAUNA FROM THE FUNERAL RANGE, DEATH VALLEY, CALIFORNIA

W. H. Easton
University of Southern California, Los Angeles, Calif.

Middle(?) Silurian fossils have been found in an un-named tributary northeast of Echo Canyon on the east side of Death Valley north of Furnace Creek Wash. This discovery extends the known distribution of bioherms of diversified Silurian faunas 50 miles southeastward from the Ebehebe Peak quadrangle. In composition the fauna resembles that from the Inyo Range more than it resembles the one from Ubehebe Peak on the west side of Death Vally. The association consists largely of rugose and of tabulate corals, but it also contains spiriferoid, pentameroid, and rhynchonellid brachiopods.

STUDIES IN THE URANIUM-LEAD METHOD OF AGE DETERMINATION

W. R. Eckelmann and J. L. Kulp
Lamont Geological Observatory (Columbia University), Palisades, N. Y.

During the past year several dozen complete age analyses have been made on samples of pitchblende, uraninites, and samarskites from a number of important localities. Isotopic ratios of Pb^{206}/U^{238}, Pb^{207}/U^{235}, Pb^{206}/Pb^{210}, Pb^{208}/Th^{232}, and Pb^{207}/Pb^{206} have been obtained for all samples where concentrations permitted. Radon leakage has been measured and corrected for as well as the common lead contamination. Several localities which have had age determinations made previously are included for comparison. Wilberforce, Ontario, remains at about 1040 m.y., Gilpin County, Colo. at 50–60 m.y., and the Besner Mine, Ontario, at about 820 m.y. New values include the Spruce

Pine, N. C., pegmatite district at about 320 m.y., Joachimsthal at about 200 m.y., and Baden, Germany, at about 110 m.y.

A large number of pitchblende samples from the Lake Athabasca region were analyzed chemically and isotopically. Apparent ages from the various isotopic ratios differ considerably. It appears possible to interpret these results in terms of radon leakage, the preferential leaching of lead during recent geologic time, and several periods of pitchblende deposition or redeposition. The oldest pegmatite deposit in the area appears to be about 1700 m.y. The oldest pitchblende which has not been subjected to later chemical effects appears to be about 1670 m.y. More recent deposition or redeposition appears at approximately 350 m.y. The data include apparent ages from specimens taken from the same level, from different levels of the same mine, and from several widely separated mines in the Athabasca district.

STUDIES OF SOME EARLY TERTIARY RED CONGLOMERATES OF CENTRAL MEXICO*

John D. Edwards
1704 English Drive, Midland, Texas

The Guanajuato conglomerate, typical of many other deposits of early Tertiary age scattered over the central and southern parts of Mexico, was studied in detail to learn its history and stratigraphic position.

The conglomerate rests on lavas of early Tertiary age, which in turn lie unconformably on deformed, intruded, and eroded Mesozoic rocks. Rhyolitic and andesitic tuffs cap the conglomerate conformably. Post-volcanic faulting, accompanied or followed by gold-silver mineralization, produced tilted blocks and grabens.

Volcanic fragments form more than half the conglomerate; other major constituents are granite, diorite, limestone, and chert. Pebble samples from 10 horizons show that volcanic, limestone, and chert fragments decrease upward in the conglomerate, whereas granite fragments increase to a maximum of 35 per cent.

The lower part of the conglomerate consists of red and brown sandstones, intercalated by andesitic and basaltic lavas and pebble beds; this is overlain disconformably by boulder beds that grade upward into pebble conglomerates. The entire sequence is about 1500 meters thick at Guanajuato city.

The source of the conglomerate was a highland northeast of Guanajuato city, composed of shales and of limestone of Cretaceous age intruded by granite and dioritic rocks and capped by a thick series of silicic volcanic rocks.

Vertebrate remains in the lower part of the conglomerate indicate a late Eocene or early Oligocene age.

Two other red conglomerates, those at Taxco and Zacatecas, were also studied.

STABILITY AND OCCURRENCE OF PARAGONITE

H. P. Eugster and H. S. Yoder
Geophysical Laboratory, 2801 Upton Street, N.W., Washington 8, D. C.

Two modifications of paragonite have been synthesized: a 1-layer monoclinic (1M) and a two-layer monoclinic (2M) form. The univariant curve for the reaction paragonite $\rightleftharpoons$ albite + 2 corundum + 2 water passes through the points 660° C.—30,000 psi water vapor pressure, 625° C.—15,000 psi, 610° C.—10,000 psi, and 580° C.—5000 psi. The point for 1 atmosphere was calculated and found to be 395° C.

* The study was under the auspices of the United States Geological Survey and the Instituto Nacional para la Investigacion de Recursos Minerales.

The two forms can readily be distinguished in powder x-ray diffraction patterns. At temperatures above 400° C. the 2M paragonite is the more stable form. All natural paragonites studied so far show a powder pattern identical with the 2M form.

X-ray studies of many natural paragonites showed that in mica schists paragonites are usually accompanied by muscovite. In these cases the powder patterns are those of mechanical mixtures of the two micas and suggest that the solid solution between muscovite and paragonite is limited. The c_0 for synthetic paragonite is 19.27 Å, and for natural paragonites an extrapolation to the end member gives c_0 = 19.15 Å. The maximum displacement of the basal spacing for a natural paragonite associated with muscovite was found to be 22 per cent of the total difference between paragonite and muscovite.

Of 90 mica-bearing schists from the Lincoln Mtn. and Hyde Park quadrangles (Vt.) 33 samples contained paragonite in amounts up to 60 per cent of the total mica content. Paragonite mainly appears in albite-free assemblages with kyanite, chloritoid, or chlorite. Staining for potassium was helpful in distinguishing paragonite from muscovite in thin sections.

CONSTITUTION OF THE NATURAL AND ARTIFICIAL DECAVANADATES

Howard T. Evans, Jr., Mary E. Mrose, and R. Marvin
U. S. Geological Survey, Washington, D. C.

When an alkaline solution of V_2O_5 is brought to a pH of about 6.5, it suddenly turns orange and, when concentrated, yields a variety of crystalline products. These products are very similar to the minerals pascoite and hummerite, which are leached out of the vanadium oxide ores in the Colorado Plateaus area by surface waters. New X-ray data have been accumulated which relate these minerals to the artificial system and throw light on their basic constitution. All data were measured on artificial crystals.

(I) $K_6V_{10}O_{28}\cdot 10H_2O$: triclinic, space group, $P\bar{1}$ (pseudo-monoclinic, I2/m), a = 17.78 A, b = 11.28, c = 17.48, β = 103°15′, Z = 4.

(II) $K_6V_{10}O_{28}\cdot 10H_2O$: monoclinic, space group, $P2_1/n$, a = 18.34 A, b = 17.42, c = 10.56, β = 94°20′, Z = 4.

(III) $Ca_6V_{10}O_{28}\cdot 16H_2O$ (pascoite): monoclinic, space group C2/m, a = 16.89 A, b = 10.20, c = 10.91, β = 93°20′, Z = 2.

(IV) $K_2Mg_3V_{10}O_{28}\cdot 16H_2O$ (hummerite; see A. D. Weeks, E. A. Cisney and A. M. Sherwood, Am. Min. *36*, 326, 1951): triclinic, space group $P\bar{1}$, a = 10.81 A, b = 11.01, c = 8.85, α = 106°04′, β = 107°49′, γ = 65°40′, Z = 1.

(V) $K_2Zn_2V_{10}O_{28}\cdot 16H_2O$: triclinic, space group $P\bar{1}$, a = 10.76 A, b = 11.17, c = 8.77, α = 104°50′, β = 109°29′, γ = 65°05′, Z = 1.

The crystal structure analysis of IV and V is in progress.

FORAMINIFERA FROM THE DEVONIAN OF NEW YORK

William R. Evitt
University of Rochester, Rochester, N. Y.

The limestones and shales of the Middle Devonian Hamilton group, western New York, have yielded abundant specimens of two new and unusual Foraminifera.

A new species of the reophacid genus *Nodosinella* from the Centerfield limestone is noteworthy because of the optical properties of the shell material. The entire test behaves optically as a single calcite crystal with optic axis parallel to the length. In plane-polarized light, absorption is conspicuously greater with the length of the test at right angles to the vibration direction of the polarizer. Secondary calcite chamber fillings, when present, are extensions of the crystal structure of the wall.

A new genus and species of attached, perforate, multilocular, finely arenaceous Foraminifera is referred provisionally to the Placopsilinidae. Collected from several Ludlowville and Moscow horizons, this foraminiferan is notable for its method of chamber addition which appears to be unique. When a new chamber was to be formed, the wall of the last chamber was mechanically ruptured. After separating along an arc of the circumference adjacent to the host surface, a segment-shaped portion of the wall was raised, cracking and hinging along a chordal line. Then a new chamber was constructed, its wall extending beneath the "lid" which had been lifted, and sealed neatly against the inner surface of the opening in the earlier chamber. Thus, despite the presence of a perforate wall, the chambers of the completed test were interconnected, not by conventional foramina, but by relatively large openings of quite different origin.

CONCENTRATION OF HEAVY ACCESSORIES FROM LARGE ROCK SAMPLES

H. W. Fairbairn
Dept. of Geology and Geophysics, Mass. Inst. Technology, 77 Massachusetts Ave., Cambridge 39, Mass.

Concentration of heavy accessories from large rock samples (circa 50 lb.) requires, in the interest of efficiency, some modification of standard techniques currently used for small samples. The Carpco induced roll separator will remove the magnetic fraction. The nonmagnetic residue is then passed through a continuous flow heavy-liquid separator which reduces handling and economizes on time. It consists of an assembly of two stainless steel beakers mounted one above another. The upper beaker contains a thin, thoroughly mixed sludge of heavy liquid and sized sand. This is fed slowly through a conical valve into the beaker underneath, where fractionation into float and sink occurs. The float is continuously removed by a jigging device, and the sink is collected after completion of the run. An improved method of washing the float consists of adding water to the sand after removal of the excess heavy liquid. This gives much greater recovery of undiluted heavy liquid than is otherwise possible and reduces the volume of diluted acetone washings which comprises the final stage.

ORIGIN OF SALT DOME SULFUR DEPOSITS

Herbert W. Feely and J. Laurence Kulp
Lamont Geological Observatory (Columbia University), Palisades, N. Y.

The application of isotopic techniques, laboratory reactions, and bacteriological studies has produced new information on the origin of the Gulf Coast salt dome sulfur deposits. Laboratory experiments designed to produce hydrogen sulfide or sulfur through the direct reduction of anhydrite by petroleum gave negative results in time equivalents of millions of years. On the other hand sulfate-reducing bacteria have been employed to produce native sulfur from dissolved sulfate. Under conditions within the range of those found in salt domes bacterial reduction caused sulfur isotopic fractionation of 1.4 per cent. This is the same order of fractionation as that observed between anhydrite and sulfur from the Newgulf Salt Dome.

These data, together with reported similarities in C^{12}/C^{13} ratios in the petroleum and in the limestone cap rock from the domes, strongly favor the theory that the reduction of anhydrite takes place by bacterial action in which hydrocarbons serve as an energy source and hydrogen sulfide is the product. The resulting sulfide is oxidized to sulfur, probably by slow reaction with the sulfate. Therefore, conditions favorable for the existence of sulfate-reducing bacteria in the anhydrite cap rock and a long average life of H_2S in the salt dome cap are both essential for the development of a commercial sulfur deposit.

CONVOLUTED BEDDING SUGGESTS TURBIDITY-CURRENT DEPOSITION IN PLEISTOCENE LAKE BONNEVILLE, UTAH

John H. Feth
Ground-Water Branch, U. S. Geological Survey, 203 24th St., Ogden, Utah

Mapping near Ogden, Utah, has disclosed convoluted beds of sand and silt. These unconsolidated strata are interpreted as deposits formed by turbidity currents within Pleistocene Lake Bonneville.

Mechanical analyses of samples from the thickest exposure of contorted beds, in West Ogden, show evidence of grading in the lower 7.5 feet of strata interpreted as the deposit of a single turbid flow. Higher, evidence of grading is not clear, although convoluted beds persist. In other localities contorted beds of sand and silt, 1 foot to several feet thick, lie between undisturbed beds of granule gravel or between undisturbed beds of claystone. The convoluted strata are found where turbid flow, following slippage from higher-lying (delta-edge?) areas during one stage or another of Lake Bonneville, can reasonably be assumed.

The limited distribution, the occurrence between undistorted strata, and the occurrence of uncontorted beds at comparable horizons immediately underlying old, now buried, soil horizons seem to preclude a Brodelböden (frost-action) origin. The large-scale contortion of the beds and absence of small-scale slump faults seem to rule out origin by penecontemporaneous soft-rock deformation.

If comparable deposits occur at depth, they probably form lenticular or wedge-shaped aquifers. It is unlikely, however, that their identity could be recognized in well cuttings or from driller's logs of wells.

FREQUENCY-DISTRIBUTION STUDY OF THE HAMILTONIAN CENTERFIELD AND TICHENOR OSTRACODE FAUNAS

Donald W. Fisher
N. Y. State Museum, Office of Paleontology and Stratigraphy, Albany, N. Y.

Collections from type localities of the Middle Devonian (Ludlowville) Centerfield and Tichenor limestones near Canandaigua, west-central New York, reveal that superficial similarities in the two faunas tend to mask existent and significant dissimilarities. Though the Tichenor megafauna is a recurrent Centerfield one, microfaunal anomalies can be demonstrated by frequency-distribution analysis. This study is based on slightly over 1300 ostracode valves from each unit.

The following modification of Dorsey's (1948, p. 269) method of illustrating relative abundance for Foraminifera was adopted for this ostracode investigation:

Percentage of total number of valves	*Frequency code number*	*Term to indicate proportion*
Over 50	6	Dominating
25–50	5	Prolific
10–25	4	Abundant
3–10	3	Common
1– 3	2	Scarce
0– 1	1	Rare
0	0	Absent

This system accentuates significant differences between 1 and 25 per cent more than those between 25 and 50 per cent, places more emphasis on lesser constituents of the fauna, and eliminates laborious specific identification, difficult in many of the ostracode genera where considerable infraspecific variation exists.

Of 25 genera found, *Beecherella* (common), *Ctenentoma* (rare), *Hollinella* (scarce), *Octonaria* (common), and a new genus (common) occur in the Centerfield but not in the Tichenor. *Ctenoloculina*

(scarce), *Hibbardella* (rare), *Thrallella* (rare), and a new genus (rare) occur in the Tichenor but not in the Centerfield. Statistical study further discloses that *Bairdia*, *Bythocypris*, and *Ropolonellus* are relatively more abundant in the Centerfield: *Amphizona*, *Euglyphella*, *Jenningsina*, and *Richina* are relatively more abundant in the Tichenor. The remaining genera are relatively distributed equally and are unimportant for differentiation.

GEOLOGICAL RESULTS OF THE 1953 TRANS-PACIFIC EXPEDITION

Robert L. Fisher, Hisashi Kuno, Ryohei Morimoto, and Noriyuki Nasu
Scripps Institution of Oceanography, La Jolla, Calif.; Geological Institute, University of Tokyo, Tokyo, Japan; Earthquake Research Institute, University of Tokyo, Tokyo, Japan; Scripps Inst. of Oceanography, La Jolla, Calif.

Principal geological findings of the Scripps Institution's 14,000-mile Trans-Pacific Expedition include:

1. Delineation of a 600-mile north-south ridge, rising abruptly from the Northwestern Pacific southeast of Kamchatka, which may join the Hawaiian Ridge. It is capped by large terraced guyots, with summits now at 600–1000 fathoms. Rocks dredged at 2900 fathoms from the base of one such guyot included (1) pebbles and cobbles of augite-hypersthene andesite, augite-pigeonite basalt, andesitic tuff and tuffaceous shales; (2) angular fragments of dacite tuff and quartz syenite porphyry; and (3) pebbles of pyroxene-hornblende dacite pumice. Petrographic and chemical analyses indicate closer affinities with Kurile Island and Kamchatka volcanic rocks than with Cenozoic Japanese of Pacific Basin types. Probably these rocks were dropped by Pleistocene icebergs.

2. Sounding profiles confirming that the Ramapo Deep, in the southern Japan Trench, is much shallower than the 5800-fathom depth formerly recorded. From west to east the trench profile shows a steep smooth drop to a narrow bottom at 5200 fathoms, a gentle rise to a broad depositional (?) surface at 4900–5000 fathoms, then an abrupt rise to 4200 fathoms, shoaling eastward to 3000 fathoms.

3. The first samples from Bayonnaise Rocks, near where the KAIYO MARU 5 was destroyed by an eruption in 1952. These rocks, with Myojin Reef, mark a submerged, periodically active volcano 225 miles south of Tokyo. The rocks are anorthite-hypersthene pigeonitic basalt characteristic of the Izu-Seven Islands volcanic zone, in contrast to the leucocratic olivine-xenolith-bearing dacite pumice ejected at Myojin.

CROOKED CREEK "CRYPTOVOLCANIC" STRUCTURE, STEELVILLE, MISSOURI

James H. Fox, Victor T. Allen, Ross R. Heinrich
Institute of Technology, Saint Louis University, Saint Louis, Mo.

The Crooked Creek disturbance is in Crawford County, about 12 miles south of Steelville, Missouri. A concentric deformed area, about 2½ miles in diameter, of Cambrian and Ordovician rocks outlines a collapsed dome partially surrounded by a ring anticline and an outer ring graben. At least 1000 feet of rocks, ranging from Bonneterre to Jefferson City, is exposed. Sedimentary rocks, considered Cherokee by some investigators, are the basis for assigning the disturbance to the interval between the Ordovician and Pennsylvanian.

The disturbance occurs at the intersection of the Palmer fault zone with the Cuba fault extension. Magnetic and gravity studies indicate that the disturbance is characterized by a magnetically and gravitationally "low" geophysical signature. This suggests the absence of dense igneous intrusive rocks and meteoritic material below the disturbed area, although post-Devonian intrusions are known in Southeastern Missouri.

The features of this disturbance are typical of Bucher's cryptovolcanic structures but are conidered to be caused by igneous activity connected with renewed movement on the Palmer and

Cuba faults that generated heat at depth and caused open fractures while the area was covered by an epicontinental sea. Sea water descended along open fractures, was heated by the magma chamber, and caused gaseous explosions that fractured, shattered, tilted, and elevated the overlying rocks. Fragments of igneous rocks were prevented from reaching the surface by the weight of sea water and overlying rocks. At depth, brecciated fragments formed a zone characterized by a density and a susceptibility deficit. Erosion of the structure followed withdrawal of the sea.

DIFFERENTIATION TRENDS IN THE LORING INTRUSIVES OF CANADA

Gerald M. Friedman
University of Cincinnati, Cincinnati, Ohio

In the Canadian Shield near the village of Loring, two basic complexes, the Caribou and Memesagamesing intrusives, are composed of norites with local picrites, pyroxenites, and olivine norites. Feldspars range from An_{68} to An_{61} in the ultrabasics and olivine norites, and from about An_{62} to An_{48} in the norites. Orthopyroxenes range from near En_{90} to En_{75} in the ultrabasics and olivine norites and from about En_{79} to En_{64} in the norites. Composition of the clinopyroxene in picrite is near $Wo_{52}En_{55}Fs_8$ and in pyroxenite near $Wo_{38}En_{52}Fs_{10}$. In the norites it ranges from near $Wo_{39}En_{51}Fs_{10}$ to about $Wo_{41}En_{42}Fs_{17}$. The olivine is near Fo_{84} in picrite and near Fo_{82} in olivine norite. The picrite contains both ortho- and clinopyroxenes, but the early norite lacks the latter. As the orthopyroxene of the norite reaches a molar percentage of En_{75} augite appears and with continued crystallization attains prominence.

A plot of enstatite content of orthopyroxene against anorthite content of plagioclase indicates a straight-line soda and iron enrichment relationship resulting from fractional crystallization and reflecting a temperature control. This linear relationship suggests an approach toward equilibrium conditions. A plot of coexisting ortho- and clinopyroxenes indicates a lineal increase of iron with progressive crystallization and suggests equilibrium conditions. In the (K_2O+ Na_2O)-MgO-FeO diagram two trends distinguish themselves—magmatic and metasomatic, respectively. The former is one of iron enrichment and parallels the MgO-FeO side, the latter was caused by later granite pegmatites and parallels the calc-alkaline trend.

ISOTOPIC ANALYSIS APPLIED TO A CLIMATOLOGICAL PROBLEM

Irving Friedman, Daniel R. Norton, A. C. Redfield, and D. B. Carter
U. S. Geological Survey, Washington, D. C.

A study of the Lake Maracaibo, Venezuela, region was undertaken to try to determine the water balance of the lake.

Hydrographic data indicate salinity in the lake is uniform and is about $\frac{1}{25}$–$\frac{1}{30}$ that of sea water. The lake is well mixed, and outflow data show that $\frac{1}{10}$ to $\frac{1}{15}$ of the lake flows out to the sea each year (22.0×10^9 m³). Inflow is about 0.7×10^9 m³/1 year.

Using Thornthwaites' method, the upland runoff and rainfall on the lake were determined as 32.2×10^9 m³ and 22.0×10^9 m³ respectively. Deuterium determinations were made on the lake, river, and ocean waters. The deuterium balance requires that 33.5×10^9 m³/yr of water evaporate from the lake. This compares with 32.9×10^9 m³ calculated from climatological data.

KUTNAHORITE: A MANGANESE DOLOMITE, $CaMn(CO_3)_2$

Clifford Frondel and L. H. Bauer
Department of Mineralogy, Harvard University, Cambridge, Mass.; New Jersey Zinc Co., Franklin, N. J.

A re-examination of type material has shown that the kutnahorite of Bukovsky (1901) from Kutná Hora, Czechoslovakia, is a valid member of the dolomite group with the com-

position $Ca(Mn, Fe, Mg)(CO_3)_2$. The material of Žák (1949) from Chvaletice, Czechoslovakia, is shown to be similar. A third occurrence is described from Franklin, New Jersey: $CaCO_3$ 51.50, $MnCO_3$ 42.00, $MgCO_3$ 5.77, $FeCO_3$ 0.73 (mol per cent); nO 1.728, nE 1.535; a_0 4.85, c_0 16.34Å; S.G. 3.12. The DTA graph and x-ray powder pattern are very similar to those of ankerite, $CaFe(CO_3)_2$. Study of 46 specimens in the calcite-rhodochrosite series from Franklin indicates that the series is incomplete under the particular genetic conditions at this locality, with a central gap extending from about 40 up to about 75 weight per cent $MnCO_3$.

A survey of the disordered calcite-type carbonates, olivine-type nesosilicates, and NaCl-type oxides of Ca, Mn, Fe, and Mg shows that in the binary systems increasing similarity in ionic size is accompanied by increasing solid solution and decreasing tendency to form ordered phases. Further, in the binary series with a central gap, $(A,B)X-(B,A)X$, the smaller ion B substitutes to a greater extent for A in (A,B)X. An ordered dolomite-type phase $MnMg(CO_3)_2$ is predicted, and a possible example is cited. The ordered phase $FeMg(CO_3)_2$ is less likely, and three specimens found with essentially this composition proved to be of the disordered clacite-type, $(Fe,Mg)(CO_3)$.

INVESTIGATION OF DOMAINS IN REORDERED MINERALS

Alfred J. Frueh, Jr.
Department of Geology, University of Chicago, Chicago, Ill.

In many compounds that have ordered after existing in the disordered state, the basic structure is essentially a single crystal, while the super structure is divided into small domains whose orientations, although bearing a rational relation to the more highly symmetric basic structure, are dissimilar.

In bornite (Cu_5FeS_4), in which little or no change occurs in the dimensions of the basic structure during disordering, the domains are of less than 1000 Å as evidenced by diffuse super-structure spots. In chalcopyrite ($CuFeS_2$), in which a pronounced dimensional change occurs during disordering, the domains are larger.

The existence of anti-phase domains has been observed in naturally-occurring chalcopyrites in rocks where cubanite unmixing has occurred and in accessory chalcopyrite in metamorphic rocks of granulite facies.

THERMODYNAMIC RELATIONS AMONG THE URANIUM OXIDES, AND THEIR RELATION TO THE OXIDATION STATES OF THE URANIUM ORES OF THE COLORADO PLATEAUS

Robert M. Garrels
U. S. Geological Survey, Washington 25, D. C.

Fields of stability of uranyl hydroxide and uranous hydroxide in water solution at 25° C and 1 atmosphere pressure have been calculated as functions of Eh and pH. Equilibrium values of the activity of uranyl ion and of uranous ion also have been calculated and are shown as contours on the stability fields. Thermodynamic relations among the uranyl hydroxides, oxides, and hydrated oxides indicate that the free-energy differences among the various species are small. The data are interpreted to mean that a variety of such uranium (VI) compounds may form and even co-exist. Similar studies of the uranium (IV) hydroxide indicate that it is unstable relative to the oxide and might well be expected to invert to the oxide at a finite rate. Uranium (V) compounds probably have a transitory existence because of the instability of the UO_2+ ion; uranium (III) oxides and hydroxides would not be expected to occur naturally because the uranium (III) ion would decompose water. A comparison of the behavior of the low-valence vanadium hydroxides (III and IV) with uranium (IV) and (VI) hydroxides indicates that vanadium (III) hydroxide should oxidize to the vanadium (IV) hydroxide at a slightly lower potential than that required for the uranous to uranyl hydroxide

pair. A speculative diagram showing probable fields of stability of many of the major minerals of the Colorado Plateaus is presented, and it is suggested that a consistent picture results if one assumes that the ores represent the superimposition of a weathering environment on a mineral assemblage formed in a primary reducing environment.

ABUNDANCE OF Sr^{87} DURING GEOLOGIC TIME

Paul W. Gast

Dept. of Terrestrial Magnetism, Carnegie Institution, Washington, D. C., and Lamont Geological Observatory (Columbia University), Palisades, N. Y.

The isotopic composition of "common" strontium from limestones and marbles of different ages has been determined. Samples include early Precambrian South African marble, middle Precambrian Grenville marble, Ordovician and Devonian limestones, and modern sea water. The change in the abundance of Sr^{87} relative to the stable Sr^{86} isotope is less than one-third of that expected (4.5 per cent per billion years) from (1) the presently accepted abundances of Rb and Sr (Rankama and Sahama, 1951) in the upper crust, (2) the decay constant of Rb^{87}, and (3) the assumption that the isotopic composition of strontium in the ocean is the same as the average isotopic composition of the strontium in crust at any given time.

From this anomaly it is clear that one or more of the above assumptions is incorrect. A critical examination of the geochemical cycle of radiogenic strontium suggests that the mixing of radiogenic and common strontium is not complete during weathering and transport to the ocean. Such an effect is in the right direction to explain the anomaly. Another possibility is that the abundance of strontium relative to rubidium is greater than the value generally accepted.

OLDER PRECAMBRIAN STRATIGRAPHY OF UPPER TONTO BASIN, CENTRAL ARIZONA

Gordon Gastil

Box 236, Alpine, Calif.

Older Precambrian sedimentary and volcanic rocks are extensively exposed in central Arizona. Previous studies have recognized formations in several areas, but their stratigraphic sequence has remained in doubt because many of the units have not been found in depositional contact.

In the Diamond Butte quadrange of the Upper Tonto Basin 10 formations of older Precambrian strata are recognized; in descending order they are:

Pronounced angular unconformity

I-IV *Four newly recognized formations;* predominantly flow and pyroclastic rhyolite; lesser amounts of conglomerate, graywacke, slate, and basic volcanic rock; 14,000+ feet

V *Newly recognized formation;* principally volcanic sandstone and conglomerate, pillow lava, basic pyroclastic rocks; 250–1850 feet

VI *Mazatzal quartzite;* quartzite conglomerate; 390–420 feet

VII *Maverick slate;* slate, graywacke, quartzite; 0–375 feet

VIII *Deadman quartzite;* quartzite, conglomerate; 380–1200 feet

Erosional unconformity

IX *Newly recognized formation;* conglomerate, basic pillow lava, rhyolite; 380–1200 feet

X *Alder formation;* slate, graywacke, quartzite, conglomerate; 5000 + (?) feet

Fault contact

Formations IV to X have been found in depositional contact and constitute the thickest continuous section of older Precambrian rocks recognized in central Arizona.

The entire exposed sequence of 20,000–30,000 feet is part of a single depositional cycle. Volcanic rocks not only constitute the bulk of the section but were the source for most of the sedimentary rocks. Despite the presence of quartzite and the prominence of rhyolite, the occurrence of graded graywacke, turbidity structures, pillow lava, soda-rich volcanic rocks, and ultrabasic intrusive rocks characterizes the sequence as eugeosynclinal.

NEUTRON-IRRADIATED QUARTZ AS A TRACER OF SAND MOVEMENTS

Edward D. Goldberg and Douglas L. Inman
Scripps Institution of Oceanography, La Jolla, Calif.

Quantitative methods of determining rates of transportation and diffusion of sediments have been limited by the lack of an adequate "tracer" of such processes. Such a "tracer" must have the same shape, size, and density distribution as one or more components of the sediment under study and must be easily distinguishable. The major radioactivity induced in quartz, irradiated in a pile, is attributed to phosphorus, contained within the quartz lattice, by decay and absorption curves. In samples containing up to a million inactive grains single grains can be readily identified by radioautographic techniques. A method has been developed whereby quartz is fractionated from the natural sediment, irradiated, and returned as a tracer to the sediment.

GEOLOGY OF THE ENGER TOWER AREA, DULUTH, MINNESOTA

S. S. Goldich, R. B. Taylor, and F. J. Lucia
Department of Geology, University of Minnesota, Minneapolis, Minn.

In connection with studies of the Duluth gabbro by the Minnesota Geological Survey, the Enger Tower area in Duluth has been mapped in detail. This area is considered representative of the upper part of the gabbro exposed in the Duluth region.

At least three periods of basaltic magma intrusion are recorded in the Enger Tower area. Anorthositic gabbro, the principal rock type, was derived in an early period. A second period of intrusion produced a zone of mixed rock types—quartz gabbro, granodiorite, and adamellite. A still later period resulted in basalt dikes.

Mesocratic uralite gabbro is a roof phase of the anorthositic gabbro contaminated with fragments of basalt flows. Inclusions of anorthosite of the Beaver Bay type may represent an older period of differentiation.

Younger rocks that intrude the anorthositic gabbro are small bodies of granodiorite and hedenbergite granophyre and dikes of granite. These rocks constitute a series whose origin is attributed to differentiation by fractional crystallization of basaltic magma. The line of descent is gabbro → granodiorite → calcic granophyre → granite.

The effects of assimilation and of contamination are considered quantitatively unimportant in producing this rock series. Inclusions have been altered to hornfels, and marginal to the main granodiorite-granophyre intrusion quartz and alkali feldspar were introduced in the anorthositic gabbro.

SODIUM CONTENT OF MICROCLINE

Julian R. Goldsmith and Fritz Laves
Dept. of Geology, University of Chicago, Chicago, Ill.

The amount of $NaAlSi_3O_8$ in solid solution in microcline (triclinic $KAlSi_3O_8$) can be determined by x-ray techniques. The *a*-axis spacing of microcline is the most sensitive to variation in the Na content, analogous to the relation in monoclinic $KAlSi_3O_8$. It is convenient to measure the (400) spacing by comparison with a simultaneously irradiated standard. The standard used here is a

single-phase, highly triclinic authigenic microcline, containing not more than 1 per cent $NaAlSi_3O_8$. Microcline has not been synthesized, so the authigenic material is invaluable for establishing the lattice constants of the pure triclinic end member.

If one assumes that the effect of Na on the *a* axis of microcline is the same as its effect on sanidine, the data of Donnay and Donnay for the high temperature series can be used to construct a curve between microcline and albite. The validity of this assumption has been checked by plotting *a*-axis values of authigenic microclines with known quantities of Na introduced. Inasmuch as the *a* axis of triclinic $KAlSi_3O_8$ differs slightly from that of monoclinic $KAlSi_3O_8$, a correction for triclinicity must be made. The correction for "fully triclinic" microcline is approximately 9 per cent for pure $KAlSi_3O_8$ and varies with Na content. Correction for microclines with intermediate triclinicity is also easily made.

Sizable amounts of Rb in some microclines can lead to erroneous values. The data on hand indicate that most microclines have exsolved virtually all of their albite; the common microclines appear to have 5 per cent or less $NaAlSi_3O_8$ in solid solution.

SIGNIFICANCE OF CARBONATE MINERALOGY IN RELATION TO THE USES OF CARBONATE ROCKS*

D. L. Graf and J. E. Lamar
Illinois State Geological Survey, Urbana, Ill.

The large-scale industrial consumption of carbonate rocks for a wide variety of uses, together with the scientific interest evoked by the natural occurrence of such rocks in most geological environments, promises to stimulate a continuing study of the fundamental properties of the principal rock-forming carbonate minerals.

Many industrially significant properties of carbonate rocks may be explained in terms of crystal structure. Anisotropism of thermal expansion and light transmission are directly related to the oxygen arrangement. Solubility and hardness anisotropy correlate with crystal structure in a more complex fashion. The ordered arrangement of Ca^{++} and Mg^{++} in dolomite requires an activation energy for disruption such that dolomite calcination, without the formation of large, unreactive MgO particles, has been a major problem. The exsolution of unstable Fe^{++} substituted for Mg^{++} in dolomite is one cause of the staining of building stones.

Ionic configuration and charge distribution at carbonate surfaces are involved in studies of the flowability of carbonate powders, the flotation concentration of carbonate minerals, and the reputed reduction of carbonate hardness during drilling through the use of surface-active agents.

Consideration of recent successful research programs on magnesite and dolomite calcination indicates that a broad attack involving knowledge of kinetics, of thermodynamics, and of crystal structures and their mechanisms of transition was necessary. A satisfactory explanation of carbonate crystal strength promises to involve imperfection theory, as well. The shortage of reliable experimental constants for carbonate minerals other than calcite is a considerable hindrance to further progress.

MAGNETIC SUSCEPTIBILITY ANISOTROPY, AN UNEXPLOITED PETROFABRIC ELEMENT

John W. Graham
Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington 15, D. C.

The maximum susceptibility of elongated ferromagnetic grains parallels their greatest dimension. The susceptibilities in all directions of a sample with many elongated ferromagnetic grains

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disseminated in a neutral groundmass can be represented by an ellipsoid whose greatest axis parallels the preferred orientation of the long dimensions of the ferromagnetic grains. An instrument which can detect differences as small as 10^{-6} cgs/cc susceptibility units has been developed for determining susceptibility ellipsoids of rocks. Two attractive features deserve mention: the measurement technique (1 hour per sample) immediately sums up the contributions of all grains, and the dimensions as well as orientations of the ellipsoid axes are determined.

Various flat-lying sediments have a nearly oblate susceptibility ellipsoid with the minimum normal to the bedding. A folded ferruginous sandstone has maximum susceptibility normal to the bedding, and the minimum is normal to the direction of the fold axis, throughout the fold. Two schists have minimum susceptibility normal to the foliation and maximum parallel to the lineation. Two diabase dikes with no obvious preferred orientation of feldspar laths have pronounced anisotropy ellipsoids that differ in the two cases in their relationships to the dike walls. Anisotropies range from 0.1 to 10 per cent; no isotropic samples were found.

These observations indicate that the final shape distortions that influenced these rocks produced dimensional orientations of the ferromagnetic grains. Thus, magnetic susceptibility anisotropy may help solve some of the problems of petrofabrics and structure.

DEFORMATION OF ROCKS AT 500°C, 5000 ATMOSPHERES PRESSURE

D. T. Griggs, F. J. Turner, and Cordell Durrell
University of California, Los Angeles and Berkeley, Calif.

Dry, jacketed specimens of various rocks have been deformed at 500°C, 5000 atmospheres confining pressure, in uniaxial compression and extension tests of short duration. Improved apparatus gives excellent reproducibility of results on the more ductile rocks.

Westerly granite tested in compression exhibits a stress-strain curve similar to that of ductile metals. Much of the deformation, however, is localized in shear zones about 1 mm thick. In these shear zones, the biotite appears to have been plastic, while the quartz and feldspar have the appearance normally associated with cataclasis.

Basalt specimens show uniform deformation, with stress-strain curves similar to that of the granite. Augite phenocrysts are twinned on the basal plane. Feldspar microlites show some bending and some fracturing. The glassy groundmass shows little effect of the deformation.

In extension tests on Yule marble, strains up to 120 per cent have been achieved without fracture. The fabric is drastically altered from that of the original, in a way that was predictable from work at lower temperature. Recrystallization does not seem to play a dominant role in this deformation. The strength of both the Yule marble and Solenhofen limestone is about half that at room temperature.

One experiment on a quartz single crystal seemed to show a small amount of plastic deformation, but other experiments have terminated in violent fracture without, however, complete loss of cohesion.

Experimental results obtained after this abstract was submitted will be described briefly.

DETAILED STRUCTURE OF NEPHELINE

Theodor Hahn and M. J. Buerger
Crystallographic Laboratory, Dept. Geology and Geophysics, Massachusetts Institute of Technology, Cambridge, Mass.

The detailed refinement has been made of the nepheline structure. This has been based on new single-crystal Geiger counter measurements of $F^2(hk\cdot 0)$ and $F^2(hh\cdot l)$. With these new data, two successive electron-density projections, $\rho(xy)$ and $\rho(xz)$, and difference syntheses, $\Delta\rho(xy)$ and $\Delta\rho(xz)$ were made. The second difference syntheses displayed an appreciable improvement in the relief

and corresponded to an improvement of the R factor. Because of overlapping in some of the atoms, no further improvement could be attained by refinement of projections. Accordingly, strategically located sections were prepared through the 3-dimensional electron density function. These syntheses made use of all new Geiger counter intensities plus additional upper-level intensities from the earlier photographic determination. The sections were synthesized on X-RAC with the kind permission of Professor Ray Pepinsky.

With these sections, the x, y, and z parameters of all atoms could be determined, and some interesting and unsuspected features of the nepheline structure were revealed: the oxygen atom, ideally on the 3-fold positions, is off the axis and statistically occupies at least two near-by sets of 3-fold positions. Another oxygen atom in the general position also appears to occupy statistically two different locations. All other atoms are substantially fixed since sections through the electron density function show these atoms to be essentially spherical.

SUBSURFACE EXPLORATION USING BUCKET-TYPE POWER AUGERS

Bruce M. Hall
Corps of Engineers, Los Angeles District, Los Angeles, Calif.

Subsurface exploration to provide geological and soils data is an important element in the investigation and design of projects constructed by the Corps of Engineers. In this respect, the Los Angeles District has found the bucket-type power auger a particularly effective and versatile exploratory tool.

The bucket-type auger is a truck-mounted earth-boring machine capable of drilling exploratory holes from 6 inches to 5 feet in diameter and to a maximum depth of 250 feet. Using conventional equipment, disturbed soil and rock samples can be taken for routine laboratory tests, and special accessories enable the taking of undisturbed samples from which the strength of the materials in place can be derived. The large-diameter holes serve as manholes that permit direct observation of the properties of the soil and rock which may be pertinent to design.

Equipment of this type is better adapted to the penetration of difficult materials than is true of the commonly used screw-type auger. Drilling mud or casing can be used where caving of the walls of the hole presents a problem. In well-indurated or bouldery soils, drill advance is facilitated by use of rock bits, mauls, or chopping bits.

Drilling versatility, mobility, ease of sampling, and comparatively low cost of exploration by this method have influenced the increasing use of the bucket auger in the Los Angeles District for securing subsurface geologic and engineering information.

PRECAMBRIAN ROCKS OF WICHITA AND ARBUCKLE MOUNTAINS, OKLAHOMA*

Warren B. Hamilton
General Geology Branch, U. S. Geological Survey, Denver Federal Center, Denver, Colo.

The Precambrian rocks in the Wichita Mountains comprise a stratiform complex in which intrusions of alumina-poor red granophyre and granite overlie gabbro and anorthosite. The complex is probably the upper part of a huge gabbroic lopolith, comparable to the Duluth and Bushveld masses, with which it shares many features. The rocks of the Wichita Mountains were probably formed in a tectonically passive environment, have not been metamorphosed, and were little deformed before the Paleozoic. Age determinations made on zircons by Larsen, Waring, and Berman indicate an age of about 640 million years for the complex.

The basement rocks in the Arbuckle Mountains consist of alumina-rich coarse-grained granite,

* Publication authorized by the Director, U. S. Geological Survey

quartz monzonite, and quartz diorite, very different in composition, structure, and association from the rocks of the Wichita Mountains. Such rocks commonly form batholithic intrusive complexes of many plutons, like much of the Sierra Nevada batholith of California; such complexes form in orogenic belts. Regional metamorphism probably accompanied the formation of the rocks of the Arbuckles.

These contrasts in petrology and inferred structural setting of the plutonic rocks of the two areas make it seem likely that rocks of the Arbuckle Mountains are older than those of the Wichita Mountains.

An episode of volcanism after the formation of the Arbuckle granitic rocks is indicated by the porphyries of the area. These porphyries may be related genetically to the rocks of the Wichita Mountains.

STUDIES IN THE SYSTEM CaO—MgO—CO_2

R. I. Harker and O. F. Tuttle
Division of Earth Sciences, The Pennsylvania State University, State College, Pa.

Apparatus has been constructed to generate and apply a high pressure (100,000 psi) of CO_2 to cold-seal quenching units.

The pt curve for the dissociation of dolomite, represented by the equation $CaMg(CO_3)_2 = CaCO_3 + MgO + CO_2$, passes through the points at 940°C and 40,000 psi, 900°C and 30,000 psi, 850°C and 20,000 psi, and 800°C and 10,000 psi. The corresponding curve for magnesite ($MgCO_3 = MgO + CO_2$) follows very nearly parallel to the dolomite curve between 40,000 and 10,000 psi but at about 50°C below it. Some runs have been made to locate the calcite curve ($CaCO_3 = CaO + CO_2$) which is thought to be at somewhat lower temperatures than those previously determined by Smyth and Adams.

The subsolidus relations in the system $CaCO_3$-$MgCO_3$ have been examined between 500°C and 900°C, and it is found that solid solutions containing up to 51 per cent dolomite in calcite are stable at 900°C and at pressures sufficiently high to prevent the dissociation of dolomite. Metastable solid solutions between calcite and dolomite have been synthesized and found to contain 64, 77, and 86 per cent of the dolomite component suggesting that complete solid solution may be stable at higher temperatures. There is evidence of slight solid solution of calcite in dolomite and of dolomite in magnesite, but the amount of magnesite in solid solution in dolomite is negligible in the 500°C to 900°C range.

PHYSIOGRAPHIC DIAGRAM OF THE WESTERN NORTH ATLANTIC

Bruce C. Heezen and Marie Tharp
Lamont Geological Observatory (Columbia University), Palisades, N. Y.

A physiographic diagram of the Western North Atlantic has been prepared using the technique developed by Lobeck. Continuous echo-sounding profiles have been taken along hundreds of thousands of miles of track by research vessels of the Woods Hole Oceanographic Institution and the Lamont Geological Observatory. These profiles have been sketched on a map at a vertical exaggeration of 20:1. Trends were noted, and hypothetical hills and valleys were drawn to complete a realistic but hypothetical picture. Although the depths and locations of the individual features are not accurately shown, the diagram clearly indicates textural relationships.

Approximately in the center of the North Atlantic basin is the Bermuda Rise, a 300,000-square mile area of undulating to moderately rough topography which rises above the surrounding abyssal plains and culminates in the pedestal of the islands of Bermuda. The abyssal plains are remarkably smooth, gently sloping surfaces which occupy the deepest portion of the ocean basin and form a nearly complete ring around the Bermuda Rise. To the east the abyssal plains are abruptly terminated against the Mid Atlantic Ridge, a wide rugged mountain range in the center of the Atlantic. To the

north and west of the abyssal plains is the continental rise, a gently sloping surface lying below the base of the continental slope. Submarine canyons dissect both the continental slope and the continental rise. South and west of the abyssal plains, a 100-mile wide ridge separates the abyssal plains from the Puerto Rico trench and the Blake Bahama basin.

RECONNAISSANCE SURVEY OF THE ABYSSAL PLAIN SOUTH OF NEWFOUNDLAND

Bruce C. Heezen, Maurice Ewing, and D. B. Ericson
Lamont Geological Observatory, Palisades, N. Y.

Abyssal plains are flat, nearly level areas which occupy the deepest portions of many ocean basins. The development of a Precision Depth Recorder was required for an effective study of the abyssal plains. In 1953 a reconnaissance survey was run on the abyssal plain south of Newfoundland. The gradient of the plain decreases from 1:1000 at its northern margin near Lat. 41°N. to 1:5000 near Lat. 32°N. South of 32°N. the gradient probably flattens still more before the southern margin of the plain is reached. The plains have been interpreted as (1) subaerial erosion surfaces, (2) atetonic areas, (3) lava plains, (4) areas of long-continued sedimentation, (5) surfaces produced by the spreading of extremely fine sediment by ocean currents, (6) areas in which the original relief has been buried by the deposits of turbidity currents. Every core obtained from the plains contains evidence of turbidity currents either in the form of graded bedding, shallow-water Foraminifera, or excessively high calcium carbonate. The plains slope away from areas adjacent to major sediment sources. The writers consider it likely that all abyssal plains represent areas in which most of the original relief is buried beneath the deposits of turbidity currents. Of the original topography only the partially buried isolated hills and seamounts remain. Continued turbidity-current transport of material into the basins continually extends the abyssal plains. The most recent turbidity current to contribute sediment to the abyssal plain south of Newfoundland followed the 1929 Grand Banks earthquake.

FLAT-TOPPED ATLANTIS, CRUISER, AND GREAT METEOR SEAMOUNTS

Bruce C. Heezen, Maurice Ewing, D. B. Ericson, and C. R. Bentley
Lamont Geological Observatory (Columbia University), Palisades, N. Y.

The Atlantis, Cruiser, and Great Meteor seamounts rise from a broad ridge or plateau which extends from the Mid-Atlantic Ridge at 37°N. 32°W. southeast to Great Meteor Seamount at 30°N. 28°W. The Atlantis Seamount, briefly explored in 1947 and 1948, was found by echo sounding and submarine photography to have a fairly flat bedrock summit area at about 180 fathoms covered in some cases by cobbles and in other cases by current-rippled sand. Its slopes are covered with sand or ooze symmetrically rippled at 400 fathoms and marked by slump features in 570 fathoms. A small piece of volcanic agglomerate was dredged from 400 fathoms on the north slope. About a ton of flat pteropod limestone cobbles was dredged from the summit area. One of the cobbles gave an apparent radiocarbon age of 12,000 years ± 900 (J. L. Kulp). The state of lithification of the limestone suggests that it may have been lithified under subaerial conditions and that the seamount may have been an island within the past 12,000 years. Oxygen isotope paleotemperature measurements made by C. Emiliani give evidence that the depth of deposition was less than the present depth of the seamounts. The Cruiser and Great Meteor seamounts studied in 1952 have larger flatter summits at 150 and 165 fathoms depth. Photographs of the sandy summits do not show ripples or cobbles. Symmetrical ripples were photographed on the slopes in depths of 1200–1400 fathoms. A reversed seismic refraction station was made on Cruiser Seamount. These youthful "guyots" may have originated as volcanoes which were later capped by limestone and more recently have sunk beneath the sea.

CENOZOIC ALLUVIAL DEPOSITS IN THE UPPER GILA RIVER DRAINAGE BASIN, ARIZONA AND NEW MEXICO

L. A. Heindl
Ground Water Branch, U. S. Geological Survey, Tucson, Ariz.

Cenozoic deposits in intermontane basins in the upper Gila River basin have been collectively included in the Gila conglomerate of Gilbert and Ransome. Re-examination of type-section areas shows that the term is unsatisfactory because it includes a substantial proportion of deposits other than conglomerates; it suggests that deposits in separate basins are identical; its use masks sequences of alluvial deposits within individual basins; and it oversimplifies a complex Cenozoic history. It is suggested that these deposits be separated into two major divisions wherever possible: an upper division consisting of conformable units, and a lower division of older Cenozoic alluvial deposits.

In each structural trough the upper division is characterized by: (1) a top erosional unconformity marked by the highest pediment surfaces; (2) depositional or normal-fault contact with adjacent mountain areas whose composition the deposits reflect; (3) size-gradation relationships that suggest deposition within the boundaries of the present structural troughs; and (4) lack of mineralization. Limited fossil evidence suggests that deposition occurred during Pliocene to Pleistocene (Aftonian?) time.

The lower division (Oligocene? to Miocene?) crops out in areas of deep dissection or structural uplift. The deposits are in fault contact with the upper division or underlie it unconformably and are characterized by: (1) texture and composition that suggest deposition in basins different from those existing during later deposition; (2) thrusting or more complex normal faulting; (3) mineralization; and (4) shallow intrusion.

Available evidence can only locally suggest correlation of units within and between troughs.

ISOTOPIC COMPOSITION OF Sr IN THE HOMESTEAD METEORITE

L. F. Herzog and W. H. Pinson, Jr.
Department of Geology and Geophysics, Massachusetts Institute of Technology, Cambridge, Mass.

The Homestead meteorite is a typical chondrite, containing 11 per cent metal phase. Sr and Rb contents, determined by optical spectrographic analysis, are: Sr = 0.0020 ± 0.0006%; Rb = 0.0013 ± 0.0004%, indicating precision of analysis only. The relative abundances of the Sr isotopes have been determined with a solid-source mass spectrometer and are the averages of 148 individual magnet-sweep, single-collector determinations. The relative abundances are: 87/86 = 0.740 ± 0.003; 87/88 = 0.0881 ± 0.0003; 86/88 = 0.1192 ± 0.0002; 84/88 = 0.0058 ± 0.0008. A single double-collector measurement agrees with these measurements. The 86/88 ratio is identical with that of standard terrestrial Sr, while the 87/88 ratio is 5 per cent greater.

Calculation of the age requires knowledge of the initial ^{87}Sr relative abundance. If this abundance was no greater than 0.0690 (the lowest value found in terrestrial rocks or minerals by our analyses) the minimum age would be 1 to 3 × 10^9 years, within the limits of uncertainty in the Sr and Rb measurements stated above. Other reasonable assumptions yield greater ages.

Analysis of a second meteorite (Pasamonte), with considerably higher Sr/Rb ratio, is in progress and may provide knowledge of the initial ^{87}Sr abundance. The Sr/Rb ratio will be determined by isotope dilution analysis.

MOULIN-TYPE "POTHOLE" IN CALIFORNIA

Charles G. Higgins
Department of Geological Sciences, University of California, Davis, Calif.

A rotating sandstone boulder on sandstone bedrock beneath an occasionally active small waterfall in Stockhoff Creek near Fort Ross, California, has worn a bowl-shaped depression 1 foot in diameter and 4½ inches deep in the bedrock. The boulder has been reduced to a discus 6 inches in

diameter and 2½ inches thick. As this "bowlhole," so different from the familiar deep irregular pothole, is the kind of broad symmetrical abrasion depression we should expect to be produced under such conditions, this occurrence tends to support recent views that most potholes result from stream evorsion or abrasion in eddies rather than from impact or abrasion by rotating, swirling, or bouncing boulders beneath waterfalls (moulin hypothesis, in part).

EXPERIMENTAL DEFORMATION OF DOLOMITE SINGLE CRYSTALS

Donald V. Higgs and John Handin
Shell Development Company, 3737 Bellaire Blvd., Houston, Texas

Jacketed cylindrical specimens of dolomite single crystals have been deformed dry under a constant confining pressure of 5000 atmospheres at a strain rate of 1 per cent per minute. Uniaxial compression and extension experiments were carried out with the stress oriented (1) parallel to the optic axis, (2) parallel to a horizontal axis *a*, (3) parallel to an edge [*f*:*f*], and (4) perpendicular to a cleavage *r*. For each orientation, tests were made at room temperature and at 300°C, and some exploratory work has been started at higher temperatures.

For orientations (1) and (2), loading results in a permanent deformation of a few per cent followed by fracture on shear surfaces inclined at about 60 degrees to the least principal stress axis at a differential stress of about 6000 kg/cm² in compression, and 3000 kg/cm² in extension. For orientations (3) and (4), there are well-defined yield points at about 2000 kg/cm² followed by large plastic strains up to 20 per cent.

Petrographic examinations, using the techniques developed by F. J. Turner, confirm A. Johnsen's discovery of translation glide on *c* {0001} along a glide line parallel to an *a* axis and confirm the direction sense (*i.e.*, negative as compared to positive sense of *e* {01$\bar{1}$2} twinning in calcite) of twin glide on *f* {02$\bar{2}$1} as first postulated by H. W. Fairbairn and H. E. Hawkes. Specifically, mechanisms are as follows: for orientation (3) translation glide on *c* {0001}; for orientation (4) translation glide on *c* {0001} and twin glide on *f* {02$\bar{2}$1} the latter restricted to deformation at 300°C and 400°C; for orientation (1) and (2) the operative mechanism not yet identified.

AGE DETERMINATIONS ON ZIRCON BASED ON RADIATION DAMAGE MEASUREMENTS

Heinrich D. Holland, William B. Head, III, and George G. Witter, Jr.
Department of Geology, Princeton University, Princeton, N. J.

Age determinations based on measurements of the ratio of radiation damage to present alpha activity have been carried out on zircons from northern New Jersey, North Carolina, Southern Ontario, and the Adirondacks. The increase in the *c* dimension of the unit cell of zircon has been used as a measure of radiation damage. The results are in good agreement with other age measurements on material of probably equivalent age and with ages found for the same materials by the lead-alpha activity method. It is concluded that radiation damage measurements in zircon can serve as the basis for a reliable method of age determination, and that the method will be particularly useful for homogeneous zircons which have received a radiation dosage between 50×10^{13} and 300×10^{13} alpha disintegrations per mg.

PERSISTENT FEATURES OF THE INNER PORTION OF THE ABLATION ZONE NEAR THE MINT JULEP RESEARCH STATION, GREENLAND ICE CAP

G. William Holmes
Arctic, Desert, Tropic Information Center, Research Studies Institute, Air University, Maxwell Air Force Base, Ala.

Immediately downslope from the firn limit on the western flank of the Greenland Ice Cap near the Arctic Circle are persistent valleys, basins, and ridges. Perennial lakes, slush fields, and streams

occur in the valleys and basins during July and early August. Stream patterns and the larger surface forms resemble those developed on bedrock, although the processes are markedly different. Valleys parallel the regional slope, which is west-northwest, and are long, broad, and oversteepened on their south-facing sides; maximum relief is 100 to 130 feet. The larger basins, also oversteepened on the south-facing side, contain lakes up to 2 miles in diameter. In July shallow basins at the valley heads near the firn limit are covered by broad, nearly impassable slush fields. The outlines of the lakes and main streams persist for periods at least as long as 4 years. The pattern of the minor tributary rills changes from year to year in response to weather. Drainage density of the intricate stream network increases rapidly downslope from the firn line. Factors which influence the development of the ice landscape in this area are: the regional slope of the ice; the absence of major crevasses which allows all runoff to remain on the ice; localized ablation in the rills, aided by concentration of cryoconite; stream erosion; high ablation on south-facing slopes; downward ablation in lake depressions; wind drift and wind deflation.

GEOLOGY OF THE PENACOOK, NEW HAMPSHIRE, QUADRANGLE

Fred S. Honkala
Geology Department, Montana State University, Missoula, Mont.

The geology of the Penacook quadrangle, a fifteen-minute quadrangle in central New Hampshire, was mapped, and a preliminary report is presented at this time. The main formation in the area is the Lower Devonian(?) Littleton formation, extensively metamorphosed, intruded, and apparently isoclinally folded. An abundance of sillimanite observed in the field indicated that much of the Littleton had undergone high-grade metamorphism, but laboratory studies are needed to determine the grade of metamorphism of the rest of the area.

Meridith porphyritic granite (?) crops out in Tilton in the northern part of the quadrangle, and Kinsman quartz monzonite (?) in the southwestern part in Webster. These lithologies may be coextensive at depth. The Concord granite in the southeastern corner of the quadrangle is a later intrusion than the above two, but all three are representative of the New Hampshire magma series, probably Devonian in age. Pegmatites and gneisses are common in the quadrangle. Some Triassic (?) trap dikes were observed. Pleistocene glacial lake deposits occupy the main stream valleys.

RELATIONS OF REGIONAL AND THERMAL METAMORPHISM NEAR THE BASE OF THE STILLWATER COMPLEX, MONTANA

Arthur L. Howland
Northwestern University, Evanston, Ill.

Precambrian granite and metamorphosed sedimentary rocks form the main core of the Beartooth Mountains in south-central Montana. A study of the relationship of these rocks to the Stillwater igneous complex along the northern border of the range has been made by the U. S. Geological Survey. In the western part of the complex the metamorphosed sedimentary rocks, largely a pelitic series, but containing some quartzite and iron formation, are adjacent to the base of the complex and extend several miles southward. To the east, granite is in contact with the base of the complex except where small patches of sedimentary rocks are preserved at the base or as masses within the granite. Thermal metamorphism by the complex precedes the regional metamorphism and the emplacement of the granite as shown by the following: (1) Close to the base of the Stillwater complex high-temperature thermal metamorphism, associated with the intrusion of the complex, has altered the pelitic rocks, presumably originally of low-grade regional metamorphic facies, to cordierite-hypersthene-biotite-quartz hornfels and the iron formation to quartz-magnetite-fayalite-pyroxene hornfels. (2) Away from the influence of the complex the sedimentary rocks are regionally metamorphosed to garnet-quartz-mica schist and are partly granitized. (3) The granite, where it lies near the thermally metamorphosed

zone, has partly converted hornfels to schist. The alteration of cordierite to sericite is the first sign of nearness of the granite.

ROLE OF WATER IN METAMORPHISM OF ROCKS IN THE CUCAMONGA CANYON AREA, CALIFORNIA

K. Jinghwa Hsu
Shell Development Company, Houston, Texas

The rocks of the Cucamonga Canyon area, California, have been subjected to two periods of metamorphism. Metamorphic rocks of the granulite facies were converted to amphibolites and mylonites in belts of intense fracturing during a post-granulite metamorphism. Mineral assemblages of the granulite facies in belts that were little deformed, however, were not altered to minerals of the amphibolite facies.

As the temperature and confining pressure during the second period of metamorphism were probably uniform over the small area about Cucamonga Canyon, the intimate association of granulite and amphibolite facies minerals suggests that local differences in vapor pressure of H_2O may have played an important role in determining the equilibrium assemblage. Thus Eskola's concept of metamorphic facies should be modified as the equilibrium assemblage of a rock of given bulk composition depends not only upon temperature and hydrostatic pressure, but also upon vapor pressure of H_2O in equilibrium with anhydrous and hydrated minerals (PH_2O), and possibly upon some other factors. This conclusion can be reached independently from thermodynamic considerations.

Water was introduced during the second period of metamorphism preferentially into the pyroxene-rich rocks, probably because PH_2O is lower for such rocks than for felsic rocks which are interbedded. Consequently, active syntectonic neomineralization (involving hydration of granulite minerals) was possible in mafic rocks, forming granoblastic amphibolites, while the felsic rocks underwent cataclastic deformation, forming mylonites.

PETROFABRIC ANALYSIS OF THE BANDED GABBROIC ROCKS IN THE WICHITA MOUNTAINS, OKLAHOMA

W. T. Huang
University of Oklahoma, Norman, Okla.

The orientation of the minerals of the Precambrian banded gabbroic rocks of the Wichita Mountains in southwestern Oklahoma is defined in terms of certain crystallographic directions and relative dimensions of the constituent grains. The results are expressed statistically as measured on three mutually perpendicular planes selected relative to the fabric plane—*i.e.*, plane of igneous lamination.

The feldspar grains have (010) faces preferably parallel to the plane of igneous lamination, but these faces have a random orientation in that plane. The clinopyroxenes and orthopyroxenes, on the other hand, show little preferred orientation.

USE OF THE GAMMA-RAY SCINTILLATION SPECTROMETER IN THE SEPARATE MEASUREMENT OF THE URANIUM AND THORIUM SERIES IN GEOLOGICAL MATERIALS

Patrick M. Hurley
Mass. Inst. of Technology, 77 Mass. Ave., Cambridge 39, Mass., and U. S. Geological Survey

A survey of the gamma scintillation spectra of the uranium and thorium series in equilibrium was made for the purpose of selecting optimum conditions for a method of direct radiometric analysis that will measure separately the quantity of these two components with moderate precision in materials

of geologic interest. A successful method has been found, utilizing the gamma radiation from Pb^{212} in the vicinity of 239 kev for discrimination of the thorium series, in comparison with a band in which the thorium series contribution is low. The circuits are sufficiently stable and the discrimination and counting rates have been adjusted to optimum values so that a comparison can be made between a band 80 kev wide centered at 239 kev and a band 60 kev wide centered at approximately 170 kev. Two channels are employed with absolute calibration of each channel at intervals that are small compared to the time of the major variations in discriminator levels.

The method can be used for materials containing as little as a few parts per million of uranium or thorium: such as, for example, most common rocks. The precision of the method and its relation to the Th/U ratio will be discussed. Samples exceeding 100 grams are used for common rock analyses. Materials containing 0.1% equivalent uranium, such as common zircons, may be analyzed in samples of 100 mg. or less.

MAGMATIC TRENDS AND ABSOLUTE AGE DETERMINATIONS OF PRECAMBRIAN INTRUSIVES OF CENTRAL TEXAS

R. M. Hutchinson, H. W. Jaffe and David Gottfried

Department of Geology, Kansas State College, Manhattan, Kans.; U. S. Geological Survey, Washington, D. C.; U. S. Geological Survey, Washington, D. C.

Harker variation diagrams have been plotted for 17 intrusions: 8 Town Mountain type with 1 associated aplite; 1 Oatman type; 2 Sixmile type; 5 aplogranites, and 1 granite porphyry (llanite).

Town Mountain type granites occupy positions of lower and intermediate silica content. Aplogranites are restricted to high-silica positions. The aplite falls within the aplogranite range suggesting the aplogranites may be late-stage differentiates of Town Mountain type granites. Llanite falls within the more acid of the Town Mountain type granites and probably is the approximate aphanitic equivalent.

Oatman type granite is interemediate between aplogranites and Town Mountain granites. Sixmile granites fail to fit the curves, suggesting a separate line of magmatic descent.

Age determinations are as follows:

Town Mountain type intrusions:	Wolf Mountain phacolith	917 million years
	Legion Creek mass	893 million years (av.)
	Enchanted Rock pluton	815 million years (av.)
Sixmile type:	Sixmile mass	822 million years
Oatman type:	Sharp Mountain mass	857 million years (av.)

Zircon samples from Wolf Mountain phacolith and Legion Creek mass gave low alpha counts compared with those from Enchanted Rock pluton and suggest a different period of intrusion or possibly fractionation with the uranium and thorium having concentrated in the younger fraction. High alpha counts of zircon from Sixmile mass and Sharp Mountain mass also indicate possible fractionation. The Town Mountain type granites probably had a common magma source, with different periods of intrusion.

Field relations confirm the age determinations. Sixmile mass crosscuts and contains xenoliths of Wolf Mountain phacolith. Enchanted Rock pluton contains xenoliths of schist recrystallized by intrusion of the Legion Creek mass.

GROWTH AND VARIABILITY IN TWO POPULATIONS OF THE MODERN BRACHIOPOD *TEREBRATELLA INCONSPICUA* SOWERBY

John Imbrie

Columbia University, New York, N. Y.

Observations by Percival on populations of terebratuloid brachiopods living at Lyttelton Harbour and Foveaux Strait, New Zealand, provide exceptionally favorable material for the study of certain aspects of growth and variability. The 700 specimens in the Lyttelton sample represent essentially

all the individuals living on four adjacent stones and include a high proportion of juveniles. Measured specimens ranging in width from 0.27 to 12.3 mm reveal an allometric length-width growth pattern. The sample from Foveaux Strait (17 specimens 8 to 22 mm in width) is more typical of paleontological collections in that it is small and biased in favor of larger individuals. Growth curves calculated for the two populations are judged to be colinear.

Although the coefficient of variability is widely employed as a measure of biological variability, its use is limited to cases in which growth stages can be distinguished. The correlation coefficient is therefore proposed as an inverse measure of variability useful in studying groups in which recognition of growth stages is difficult. The growth curve and correlation coefficient of the bivariate distribution are thus considered analogous to the mean and coefficient of variability of the univariate distribution. Application of this concept shows that the Lyttleton population decreases in relative variability with growth. This decrease is attributed to centripetal selection pressure.

WAVE-GENERATED RIPPLES IN NEAR-SHORE SANDS

D. L. Inman and W. W. Scott
Scripps Institution of Oceanography of the University of California, La Jolla, Calif.

A study of ripple formation by oscillatory wave motion was made in the coastal waters of southern California to gain a better understanding of the role ripples play in the mechanics of sand transport and to aid in interpreting fossil ripple mark. Swimmers equipped with self-contained breathing apparatus extended the observations from the surf zone to depths greater than 100 feet. The wave length, crest length, height, and symmetry of the ripples were measured, and these parameters compared with the size of the sand and with the orbital displacement and velocity of the wave motion generating the ripples.

Ripples were always present on sandy bottoms when the significant orbital velocities exceeded about 0.3 ft./second. The type of ripple was related to the size of the sand and the nature and rigor of wave motion. The ripple wave length ranged from about 0.2 foot where the sand size was 0.1 mm to about 3.0 feet where the sand size was 0.5 mm. The corresponding heights of the ripples ranged from about 0.02 to 0.5 foot.

The form of the ripple profile tends to imitate in miniature the form of the profile of the surface wave generating it. In deeper water where orbital velocities are lower, and the wave profile is approximately trochoidal, the ripples tend to be trochoidal. In shallow water where velocities are higher and the wave forms are solitary, the ripples consist of isolated crests separated by flat troughs.

URANIUM DEPOSITS, BIG INDIAN WASH-LISBON VALLEY AREA, SAN JUAN COUNTY, UTAH

Y. William Isachsen
1001 Ute Avenue, Grand Junction, Colo.

Extensive bedded uranium deposits discovered about 32 miles south-southeast of Moab, Utah, occur in sediments along the southwest limb of the Lisbon Valley salt anticline. The major ore bodies are confined to the lower portion of the Triassic Chinle formation which unconformably overlies the Permian Cutler formation. Arkosic, gray to black sandstones with intercalated lenses of gray-green mudstone and mudstone pebble conglomerate contain uraninite which has replaced carbonaceous material and calcite cement. Montroseite occurs with uraninite in the major deposits discovered to date. Tyuyamunite frequently forms surface coatings along fractures. Thickness of ore in the area is generally sufficient to permit mining with little or no waste rock.

In several areas known to contain ore bodies, the gray-green color of the lower Chinle formation extends upward into the overlying red Chinle mudstones in the manner of an alteration halo. About

100 feet beneath the Chinle ore horizon are arkosic lenses in the Cutler formation which contain, in some instances, low-grade uranium mineralization. The ore minerals, carnotite and becquerelite, are disseminated in the arkose with greatest concentrations frequently adjacent to fractures.

TEXTURAL RELATIONS OF CRYSTAL ACCUMULATES IN THE ULTRAMAFIC ZONE OF THE STILLWATER COMPLEX, MONTANA

Everett D. Jackson
U. S. Geological Survey, Menlo Park, Calif.

The igneous Stillwater complex is a differentiated layered intrusion at least 18,000 feet thick exposed for 30 miles along the front of the Beartooth Mountains, Montana. The lower 3500 feet of the complex is composed of rhythmically stratified ultramafic rocks that exhibit both igneous and sedimentary textures. Mineral grains in the rocks can be divided into two types: individual euhedral crystals and negative-shaped grains interstitial to these crystals. Variations in size, shape, and composition of the well-formed grains are related to, and in many instances define, the layering. The interstitial material occurs in single grains or oikocrysts that are independent of the layering. The euhedral grains crystallized from the main magma and settled to the floor of the magma chamber; the interstitial grains crystallized in place from magma surrounding the settled crystals. The composition of the settled minerals is peridotitic: only olivine, orthopyroxene, and chromite occur as euhedral individuals. The composition of the interstitial material is gabbroic: plagioclase, orthopyroxene, and clinopyroxene are the principal minerals. Where settled crystals were "cemented" by interstitial material belonging to a different reaction series, the original porosity of the crystal mush ranged from 20 to 40 per cent. Where settled crystals were secondarily enlarged or resorbed after accumulation by interstitial material belonging to the same reaction series, the rocks developed xenomorphic and hypautomorphic textures.

UPPER MISSISSIPPIAN-LOWER PENNSYLVANIAN ROCKS, SOUTHERN EGAN RANGE, NEVADA

John W. James
245 West 107 Street, New York, N. Y.

In the southern Egan Range, east-central Nevada, rocks of Late Mississippian and, possibly, early Pennsylvanian age consist of approximately 1000 feet of dark-gray to black, marine shale, which grades upward into 200–300 feet of reddish-brown weathering quartzite and quartzitic sandstone. The shale conformably overlies a succession of coarse-grained and crinoidal, to fine-grained and argillaceous, limestone beds which are correlated with the Joana limestone of the Ely District. The quartzite and quartzitic sandstone in the upper part of the section grades upward into shaly and sandy limestone beds equivalent to the Ely limestone of the Ely District.

Though the quartzites and quartzitic sandstones contain scattered casts of plant fragments, and marine fossils are quite rare, they are probably of shallow marine origin because: (1) individual beds range between 1 and 3 feet thick and are consistently tabular, (2) the coarser-grained portions are cross-laminated and are truncated at the top by regular planes, (3) the finer-grained portions display "current-ripple" or "feather cross-lamination" in cross section, (4) both current and oscillation ripple marks are common and (5) cross-limination planes, in any selected bed, dip consistently.

Statistical studies of cross-lamination planes indicate the predominate current flow was from north-northeast. Although the quartzites are believed to be nearly time-stratigraphically equivalent to the Diamond Peak quartzite of the Eureka District, they are not interpreted as a direct eastern facies. Rather, they are thought to have been derived from a more northerly source.

INVESTIGATION OF TUNNEL ROUTES THROUGH THE TEHACHAPI MOUNTAINS FOR STATE OF CALIFORNIA'S FEATHER RIVER PROJECT

Laurence B. James
California Division of Water Resources, State Building, Los Angeles, Calif.

The Feather River Project, authorized by the California Legislature and designed to convey surplus flood waters from northern California to areas of deficiency in southern California, is being investigated by the office of the State Engineer.

The proposed project includes a dam on the Feather River near Oroville, 711 feet in height with a reservoir capacity of 3,500,000 acre feet, 290 miles of canal along the west side of San Joaquin Valley, with an available continuous supply of 3930 second feet, tunnels through the Tehachapi Mountains, and about 280 miles of conduit through southern California to the Mexican border.

A critical section of the conduit is the tunnel through the Tehachapi Mountains, about 65 miles north of Los Angeles. Four possible tunnel routes through this region of high seismic activity are under consideration. Two lower-elevation routes would cross six major faults including the recently active San Andreas and also the Garlock. Two higher routes would avoid these two faults but would necessitate higher pumping lifts and consequently greater continuing energy costs.

Igneous, metamorphic, and sedimentary formations occur in the Tehachapi Mountains. The existence of numerous springs and fractured rock portends underground water problems particularly along the lower routes, where high pressures and temperatures are predicted. Need for heavy tunnel support is anticipated at fault crossings and near tunnel portals. Potential oil- and gas-bearing structures exist in the sedimentary formations crossed by the three lower routes.

Extensive subsurface exploration, including core drilling and adits, is now in progress.

GEOLOGICAL HISTORY OF WEST COAST OF VANCOUVER ISLAND AND QUATSINO SOUND*

J. A. Jeletzky
Geological Survey of Canada, Victoria Memorial Museum Bldg., Ottawa, Ont., Canada

The following is the summary of geological history of the area (all thicknesses in feet):

Age		Beechey Head-Clayoquot	Clayoquot-Brooks Peninsula	Quatsino Sound
Neogene				
(?) Lower Miocene		Sooke formation (= Upper Blakeley)	Sooke sandstones. ±150–200	
Upper	Oligocene	Carmanah formation (= Lincoln + Lower Blakeley stages)	Lower Blakeley sediments, 4000–5000 or (?) more	
Middle	Oligocene		Lincoln sediments. ±3000	
Lower	Oligocene	Major orogeny. Sooke intrusives		
Eocene		Metchosin volcanics		

* Published by Permission of The Deputy Minister, Department of Mines and Technical Surveys

Age	Beechey Head-Clayoquot	Clayoquot-Brooks Peninsula	Quatsino Sound
Paleocene and Upper Cretaceous unknown			
Lower Cretaceous			Aptian or (?) Albian shales and sandstones. Probably ± 1000
			Aptian conglomerates. ±2000
		Lower Neocomian marine sediments. ±800–1000	Lower Neocomian to Upper Barremian or (?) Lower Aptian marine sediments. 600 or more
Jurassic — Upper		Erosional disconformity	
		Middle Callovian to Portlandian marine sediments. ±2000	
Middle	Major orogeny. Batholithic Coast intrusions. Middle Jurassic strata unknown.		
Jurassic — Lower	Undivided volcanic and sedimentary rocks of Vancouver group. Leech River sedimentary rocks and Malahat volcanics more probably Triassic or lower Jurassic than Palaeozoic	Volcanic Bonanza group: Toarcian sediments. ±2000	
		Volcanics with intercalated sediments. Precise correlation with Quatsino Sound not possible. Probably 5000 or more.	Volcanics and minor sedimentary rocks. ? 1000 or more.
			Plensbachian shales. 800 or more.
			Volcanics. (?) 500 or (?) more.
			Sinemurian shales. 800–1000 or (?) more.
		Hettangian and (?) locally Rhaetian volcanics and intercalated sedimentary rocks. Probably 5000–7000 or (?) more.	
Upper Triassic and (?) possibly older		Locally unconformity / Norian and (?) locally Latest Karnian sedimentary part of Bonanza group. ±2000–2500. / Upper Karnian and (?) locally Lowermost Norian Quatsino limestone. 150–1500 or more.	
		Karnian and (?) older Karmutsen volcanics. Probably up to 5000 visible. Bottom not seen.	

IGNIMBRITES IN SOUTHERN PERU

W. F. Jenks and S. S. Goldich
University of Rochester, Rochester, N. Y.; University of Minnesota, Minneapolis, Minn.

Ignimbrites near Arequipa were described in 1948 by Fenner and by Jenks. The ignimbrite (sillar) outcrops in 12 per cent of the Arequipa quadrangle. It also occurs extensively in the Departments of Moquegua, Puno, Cusco, and Abancay, southern Peru.

Many tuff flows are related to an early phase of the present stream pattern. Single flows have been traced down valleys for 30 km: in the headwaters they occupy valley bottoms; in the lower reaches valleys have been incised as much as 700 m below the base of the tuff flows, leaving the flows on remnants of a mature surface. Thus these eruptions are related to the Chacra mature valley erosional stage and were the last events before the rejuvenation which produced the present deep canyons.

Whereas the bulk of the Tertiary to Recent volcanics is andesitic, the sillar is rhyolitic. The sillar appears to have been a near-terminal phase of a long history of andesitic eruptive activity. The sillar in turn is locally covered by dominantly andesitic rocks of the latest cycle of vulcanism.

The sillar was erupted from diverse, dominantly andesitic volcanic massifs, but specific vents have not been found.

Ignimbrites of the Arequipa region are not welded. The hardness of those which are largely devitrified was attained by crystallization and cementation while the tuff flows were still hot, with the production of textures like those of previously described ignimbrites. Initial toughness of the ignimbrites is attested by their permanent displacement of major streams.

CORRELATION OF BASALT FLOWS IN CENTRAL NEW MEXICO BY FUSION TECHNIQUE*

Henry L. Jicha, Jr.
New Mexico Bureau of Mines and Mineral Resources, Campus Station, Box 27, Socorro, N. M.

Late Tertiary and Quaternary basalt flows of at least five ages from seven vents lie upon various surfaces in the Cerro Verde quadrangle, 50 miles northwest of Socorro, New Mexico. The flows consist of olivine, augite, labradorite, magnetite, and glass and average about 48 per cent silica.

Powdered samples were fused in a carbon arc according to the method of Matthews, and refractive indices of glasses thus formed were determined to 0.001. Indices of 50 samples determined in the study range from 1.608 to 1.583. Duplicate fusions show that indices are reproducible to 0.002.

Each flow has a specific range of refractive index not exceeding 0.015. Where these ranges do not overlap markedly, isolated flow remnants can be correlated on the basis of five or less samples. Vent rocks may also be correlated with flows derived from them.

The indices for three superposed flows from one vent are significantly different; each succeeding flow is more silicic. Statistical analysis shows that the probability of obtaining such variations from one population is less than 0.004.

The rapid fusion technique furnishes adequate basis for local correlation of basalt flow remnants as well as for correlation with filled vents. In all these samples compositional differences do not appear to be large enough to be revealed significantly by chemical analysis.

MONOCLINES

Vincent C. Kelley
University of New Mexico, Albuquerque, N. M.

The contemporary definitions of a monocline are typified by that of Lahee—"a steplike bend in otherwise horizontally or gently dipping beds." Singleness of direction of dip and great ratio of length to width are additional attributes.

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In many provinces monoclines are of great length and are the dominant structure. In such regions reversal of dip of a broad or locally abrupt nature commonly occurs near the head or foot of the monocline. This should not be cause for dropping the monoclinal designation.

In some regions moderate dips are locally interrupted by steep dips, and these structures also should be termed monoclines. Therefore, the monocline is not *"a steplike bend"* because the beds above and below may be inclined, and in addition the structure consists of *two bends* (Busk's anticlinal bend and synclinal bend). ***A monocline is a double bend involving local steepening in otherwise gently to moderately dipping layers.***

Monoclines may be described as gentle or steep, narrow or broad, open or closed, level or plunging, overturned, buckled, broken, thrust, etc. The following classification is suggested:

Diastrophic Types
- By dominantly noncompressional forces
  - Straight monoclines
  - Curving monoclines
  - Horstlike monoclines
  - Grabenlike monoclines
  - Monoclines with vertical or normal faults
  - Half monoclines ?
- By dominantly compressional forces
  - Curving monoclines
  - Buckled monoclines
  - Overturned monoclines
  - Monoclines with thrusts
  - Half monoclines ?

Nondiastrophic Types
- Draped over margins of solution-collapse areas
  - Sinuous monoclines
  - Circular monoclines—facing inward
- Differential compaction monoclines
- Intrusion monoclines—over sill or laccolith margins
- Lava-cascade monoclines

STRUCTURE OF THE SANDIA MOUNTAINS, NEW MEXICO

Vincent C. Kelley and Charles B. Reynolds
University of New Mexico, Albuquerque, N. M.

The Sandia Mountains are an eastward-tilted north-south uplift about 20 miles long, lying about 10 miles east of Albuquerque. They form a short but prominent part of the eastern rim of the great Rio Grande Trough. The bold western escarpment of the mountains rises 5000 feet above the Rio Grande Valley. The Precambrian rocks of the escarpment consist largely of granite, but quartzite, schist, gneiss, and greenstone are present at the north and south ends. Some 9000 feet of sedimentary rock, ranging in age from Mississippian (?) to late Cretaceous, lies unconformably on the Precambrian in the eastern slope and foothills. Structures on all sides are complicated.

The mountains probably were elevated first by late Laramide eastward upthrusting along a line of buckles and high-angle faults east of the present crest. Folding and high-angle faulting continued the uplift during late Miocene and Pliocene time, at the end of which about 10,000 feet of sediments had accumulated in the trough to the west.

Toward the end of the Pliocene, north-south coupling action produced left-lateral movement along

the frontal fault and on the Tijeras fault along the southeast side of the range. These faults show strong drag and offsets (as great as 3 miles) of vertical structures. The Pliocene sediments adjacent to the frontal fault are severely buckled. The concept of a simple, tensional, basin and range fault block should be abandoned. The range and the adjoining trough are a part of the Eastern Rockies.

GEOLOGY OF THE VILLAREAL UPLIFT, SIERRA DE TLAHUALILO, COAHUILA, MEXICO

Lewis B. Kellum
Museum of Paleontology, University of Michigan, Ann Arbor, Mich.

This paper is a contribution to the dating of diastrophism, vulcanism, and sedimentation in northern Mexico. The Villareal uplift is a second-order structural feature on the major Sierra de Tlahualilo anticline. Stratigraphic and paleontologic studies of the Lower Cretaceous Aurora limestone enable one to understand details of structure not otherwise revealed. The Aurora limestone is grouped into six lithologic units for mapping and interpretation. The discovery of three faunal zones in the Aurora limestone permits their correlation with zones in the Washita and Fredericksburg of Texas. Facies changes are described.

The Villareal uplift is a prominent dome which brings to the surface, in the rugged canyons at its crest, the gypsum-dolomite Cuchillo series, underlying the Aurora limestone. The dome is bounded on the north by a nearly circular structural depression, about 2 miles in diameter, called the Gonzalez Basin, and on the south by the Guayule Embayment.

A normal fault begins on the western flank of the Villareal Uplift and extends northward. It has a displacement of 450 feet where it crosses the Gonzalez Basin and is clearly post-Lower Cretaceous and probably post-Cretaceous.

Two small areas of volcanics on the northwest and south flanks of the Villareal Uplift were deposited after the main period of orogeny that deformed the Cretaceous limestone. The preservation of volcanics in erosional depressions of the underlying limestone indicates that folding, uplift, and erosion of the limestone preceded the volcanism. The prevolcanic erosion surface is being exhumed by present-day erosion.

USES OF CLAY IN THE DEVELOPMENT OF WATER RESOURCES

George A. Kiersch
University of Arizona, Tucson, Ariz.

Clay materials are attaining new importance in developing and conserving water resources; techniques to utilize the expanding properties are under investigation currently by several groups. In evaluating the widespread clay deposits of the Navajo country, Arizona, for potential marketing several uses in connection with water resources of the Southwest became apparent.

The concept of clays as colloidal electrolytes that dissociate when dispersed in water generally explains the significant relation between degree of swelling on hydration and the composition of the clay minerals. Natural clays in the range of montmorillonites to kaolinites swell; a mixture of the minerals and/or artificial treatment to stimulate dispersion or cation exchange may enhance the swelling phenomena.

Some small valleys are "drained" of ground water in their upper part owing to a steep gradient or heavy drawdown. The permeable or open-void gravel zones in the valley fill can be sealed off by grouting with a slurry of swelling clay. The void-filled sand, silt, and gravel "take" little slurry. This underground dam retains ground water for local production and retards migration.

Catchment basins and canals can be lined to reduce influent flow into a pervious bed zone of rock

or noncohesive material. Utilization of a sediment mixture is controlled by: (1) composition of slurry; (2) gradient; (3) water quality; (4) dilution effect of clear water; and (5) method of applying charges.

Swelling clays are ideal because they: (1) are self-sealing; (2) are inexpensive; (3) are good void-fillers; (4) stabilize weakly consolidated material; and (5) can be applied as dispersed or flocculated particles depending on sealing requirements.

AREAL VARIATION IN LOW-LEVEL RADIOACTIVITY OF SOME PENNSYLVANIAN BLACK SHALES

W. C. Krumbein and H. A. Slack
Department of Geology, Northwestern University, Evanston, Ill.

Black shales in Pennsylvanian cyclothems in the western part of the Illinois Basin are remarkably uniform in thickness and lithologic properties over large areas. The shales show a low radioactivity as measured by alpha particle emission. The purpose of this study is to determine whether the shales are regionally uniform in this attribute. Preliminary studies showed a ten-fold variability in radioactivity along closely spaced samples, and the geological problem became one of designing a sampling plan which could furnish reliable estimates of regional changes in radioactivity without requiring large numbers of closely spaced samples. Multilevel sampling, involving a hierarchy of "supertownships", townships, strip mines, and sampling spots within the mines permitted estimates of the amount of variation introduced at each sampling level, as well as the setting up of confidence limits for means in the whole area.

The black shale overlying Coal No. 6 was selected for study. Strip mines, mine dumps, and some by test-well cores supplied about 175 samples for a regional study extending 200 miles along the outcrop belt. These samples were supplemented by a number of closely spaced samples on grids laid in strip mines to determine more accurately the variability within and between adjacent mines. Present results of the study indicate that, although the radioactivity of this black shale varies noticeably from sample to sample within a single strip mine, there is no definite evidence of a strong regional trend along the outcrop belt.

PALEOGEOGRAPHIC SIGNIFICANCE OF ORIENTED DEPOSITIONAL PHENOMENA IN KULM GRAYWACKES (LOWER CARBONIFEROUS), CENTRAL GERMANY

Ph. H. Kuenen and John E. Sanders
Geologisch Instituut, Groningen, Nederland; Department of Geology, Yale University, New Haven, Conn.

The Kulm graywackes (Lower Carboniferous) of central Germany abound with oriented depositional phenomena which have been measured and plotted. Association of graded bedding and uniform stratification with current ripples, small-scale cross-lamination, flow marks, drag marks, slide marks, several varieties of lead-cast phenomena, convolute bedding, subaqueous slump structures, aligned plant fragments, aligned fossil shells, and oriented grains leads the authors to infer deposition in deep water by turbidity currents. Study indicates direction of currents and movement of material from north-northeast to south-southwest, parallel to the inferred axis of the trough. The inference of an east-northeastern source is strengthened by the occurrence in areas northeast of the graded graywackes of coarse-grained Kulm sandstones containing characteristic features common to shallow-water deposits. Direction of current flow, therefore, is demonstrated to have been directly from an area of shallow-water deposition. Rough calculations of depth based on the relative positions (graded beds vs. shallow-water deposits) and on assumed bottom slopes suggest 2000 meters.

The authors agree with Hoeck (1928) and Fiege (1937) *re* a northeastern source of sediment but

disagree with the northern source postulated by Pickel (1937). The interpretation of deposition of the coarse débris in deep water contrasts with previous conclusions that Kulm graywackes occurred in a shallow sea adjacent to a coast. Explanation of graded bedding by turbidity-current mechanism also contrasts with tectonic and climatic interpretations, assigned by Fiege (1937; 1951).

VARIATION IN THE ISOTOPIC COMPOSITION OF COMMON LEAD

J. Laurence Kulp and George L. Bate
Lamont Geological Observatory (Columbia University), Palisades, N. Y.

New measurements of the isotopic composition of lead from some 120 lead minerals are reported. Some of these samples have been measured in several laboratories using Pb^+ from PbI_2, Pb^+ from $Pb(CH_3)_4$ and $Pb(CH_3)_3^+$. In general the agreement is excellent, indicating the absence of appreciable systematic error in any of the techniques.

This large increase in the data on common lead makes it possible to begin to predict the range in isotopic composition of lead from various geological settings. This is important for age determination and for the understanding of the mechanism of emplacement of lead ores. In the Joplin District the range in 207/206 is at least 4 per cent, in the Wisconsin-Illinois-Iowa District at least 9 per cent, and in Southeast Missouri 15 per cent, although samples from opposite ends of a single crystal of galena showed no differences. The precision of measurement is 0.1 to 0.2 per cent. These data strongly suggest that these leads were not derived from the mantle.

Variations in the isotopic composition of common lead from pegmatites in well-defined geological provinces such as New England or the Southern Appalachians appear much smaller. A few interesting exceptions to the regional pattern appear; one such exception occurs at Franklin, New Jersey.

The rough correlation of the isotopic composition with age persists. The new data do not greatly affect the calculation of the age of the earth but do help delimit the area of application of the "galena age method".

RECONNAISSANCE GEOLOGY OF THE SOUTHEASTERN MOJAVE DESERT, CALIFORNIA

Donald H. Kupfer and Allen M. Bassett
U. S. Geological Survey, Claremont, Calif.

The geology of an area covering 3500 square miles in southeast San Bernardino County, California, was mapped in 4 months using aerial photographs and jeep reconnaissance. The area includes the northwest-trending Cady, Bristol, Bullion, Sheephole, and Coxcomb mountains. Although each part of the area has its own stratigraphic section and local unconformities, the regional history is one of continuous orogenic, volcanic, depositional, and erosional activity during Cenozoic time.

The Cenozoic rocks are dominantly volcanic at the base and clastic at the top and lie unconformably on undifferentiated plutonic and metamorphic rocks. Pyroclastic rocks of intermediate composition are overlain by a thick series of andesite flows, which grade upward into basaltic andesites (plagioclase An_{50}) and then into olivine basalts. Cones of the latest basalt flows are essentially uneroded. Rhyolite flows with associated perlite are interbedded with the basaltic andesites.

Faulting, tilting, and minor folding were continuous throughout late Cenozoic time. The principal faults trend northwest, dip steeply, and are 1 to 6 miles long. Several of these shorter faults are alined in such a way that their ends overlap, and they seemingly form single breaks more than 50 miles long.

Physiographic features suggest that during late Cenozoic time drainage from the western Mojave Desert crossed the area and joined the Colorado River. If so, the drainage was broken up, and the

present playas were formed and were filled to their maximum heights before the time of the latest basalt flows. The playas have since been deflated 3 to 10 feet.

AGE OF THE BIDAHOCHI FORMATION, ARIZONA

John F. Lance
Department of Geology, University of Arizona, Tucson, Ariz.

The Bidahochi formation in northeastern Arizona has been considered in part as of Hemphillian (Middle Pliocene) age on the basis of the fossil beaver, *Dipoides*, from the White Cone local fauna in the Hopi Buttes. *Dipoides* is now known to range upward into the Pleistocene, but recent discovery of mylagaulid teeth at White Cone strengthens the Hemphillian age assignment. A new fauna from the Bidahochi formation in Graywater Wash, near Sanders, Arizona, discovered in 1953 by Paul W. Howell of the University of Arizona contains *Merycodus*, ? *Gomphotherium*, and a large camleid, suggesting either a Clarendonian (Lower Pliocene) or a Barstovian (Upper Miocene) age. The fossils are from a silty sandstone directly overlain by bentonite. Exact stratigraphic relationships of these beds to those in the Hopi Buttes are not known, but the age of the Bidahochi formation can now, on the basis of fossil evidence, be extended downward at least into the Clarendonian.

RELATIONS OF POTASSIUM, BROMINE, AND IODINE IN MARINE SALINE SEDIMENTATION

Walter B. Lang
U. S. Geological Survey, Washington, D. C.

Quantitative relations of potassium, bromine, and iodine in sea water are known only for the present seas. Assuming that the composition of Permian seas was that of the present sea, then the concentration of potassium was six times that of bromine and some 7000 times that of iodine. However, bromine as well as iodine appears only in fractional percentages in a marine potash deposits, with sylvite, carnallite, and residual liquors generally containing the largest amounts. These relative amounts show a degree of similarity for deposits the world over.

Halite of the Salado formation contains on the average 0.02 to 0.03% of bromine and 0.4% of potassium. Where potash deposits of polyhalite (15.6% K), sylvite (52.4% K), langbeinite (18.8% K), or carnallite (14.1% K) formed, only sylvite and carnallite contain as much as 0.25% bromine. Thus the Salado formation is deficient in bromine with respect to potassium as present in modern sea water. There is no obvious chemical means for its escape from the evaporation system as is available for iodine, which can be volatilized when heated in the presence of ferric iron. By the law of averages decantation is not a likely explanation, for the terminal stage of the numerous rhythms of saline sedimentation is always the same.

Thus the assumption that the Permian sea contained bromine in the same ratio to potassium as modern seas may be in error, or bromine may have escaped from the basin by some mechanism not now known.

STRATIGRAPHY OF THE GIRON FORMATION, DEPARTMENTS OF SANTANDER AND BOYACA, COLOMBIA, SOUTH AMERICA*

R. L. Langenheim, Jr.
Department of Paleontology, University of California, Berkeley, Calif.

Nonmarine arkosic conglomerate, arkose, siltstone, and mudstone of the Giron are unconformable above Carboniferous, Devonian, or Precambrian rock and unconformable beneath widespread Lower

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Cretaceous coarse clastic rocks. An eastern, redbed facies containing cycads or conifers is well exposed between Bucaramanga and the Chicamocha gorge. A western, nonoxidized facies outcrops over the Lebrija highland west of Bucaramanga. The new type section, between railroad Km. 94.200 and 107.823 in the Lebrija gorge, is disconformable beneath red Cretaceous conglomerate, angularly unconformable above the Carboniferous Bocas formation, and is divided into upper (1227.5 m) and lower (779.5 m) coarse units separated by fern-bearing siltstone, mudstone, and arkose (2065.6 m). In the Arcabuco Range, on the Duitama-Charalá road, an upper red arkose unit is exposed on the southeast above a black mudstone and siltstone unit containing abundant estherids, ostracodes, freshwater mollusks, ferns, cycadeoids, and macerated plants exposed in the core of the range.

The pre-Cretaceous unconformity is marked by local angularity, truncated faults and intrusions, basal conglomerate, and Cretaceous overstep in the Chicamocha gorge. Elsewhere appearance of well-washed sandstone or Giron pebble conglomerate distinguishes disconformable contacts. Between Duitama and Bucaramanga the basal Cretaceous sandstone is a massive, cliff-forming unit with few red beds or fine beds. Much red mudstone and conglomerate appear, however, in this unit in the Lebrija highland.

Triassic age is suggested for the Giron, but Pennsylvanian to earliest Cretaceous rocks may be included.

AGE OF THE SOUTHERN CALIFORNIA, SIERRA NEVADA, AND IDAHO BATHOLITHS

E. S. Larsen, Jr., David Gottfried, H. Jaffe, and C. L. Waring
U. S. Geological Survey, Washington, D. C.

The ages of rocks from three batholiths have been determined by the lead-alpha activity ratios on the accessory minerals zircon, monazite, and xenotime. On the basis of geologic evidence those from the batholith of southern California have been determined as early Late Cretaceous in age. Twenty-five age determinations on rocks ranging from quartz diorite to granite give an average age of 105 million years. Seven age determinations on rocks from the Sierra Nevada batholith give an average age of 100 million years. On geologic evidence the Sierra Nevada batholith is believed to be Late Jurassic. Five age determinations on rocks from the Idaho batholith average 103 million years. This batholith has been geologically dated as Cretaceous. The age of the three batholiths as determined by the lead-alpha activity method is essentially the same and is about 102 million years.

ORIGIN OF VERMICULITE DEPOSITS, SOUTHERN VIRGIN MOUNTAINS, NEVADA

F. Beach Leighton
Whittier College, Whittier, Calif.

Vermiculite deposits lie within a 1 mile square area in the Gold Butte mining district, Southern Virgin Mountains, Nevada. They occur in ultramafic sheets and lenses of probable Precambrian age. Peridotites and perknites have intruded Precambrian migmatites, granulites, and quartzites and now crop out in the interior of an elliptical dome. Vermiculite is widely distributed in the ultramafic rocks in veins, stringers, pockets, and as scattered flakes.

All vermiculites present must be considered varieties of hydrobiotite, because K_2O is present in every case and represents a contamination by biotite layers. The fact that all samples showed either biotite interleaved with vermiculite, or nonexpandable biotite along with hydrobiotite is one of the best evidences that all vermiculite has altered from biotite, which, in most cases, is an intermediate product in the alteration of other ultramafic minerals.

Vermiculitization of biotite was largely accomplished by hydrothermal solutions associated with the injection of abundant granitic pegmatites. However, it is believed that meteoric solutions continued the process of vermiculitization after hydrothermal activity ceased and, perhaps, in some cases initiated it.

GEOMORPHOLOGY OF THE JUNCTION OF THE UPPER AND THE LOWER MISSISSIPPI RIVER VALLEY*

M. M. Leighton and H. B. Willman
Illinois State Geological Survey, Urbana, Ill.

One of the most striking features of the geomorphology of the United States is the junction of the constricted upper Mississippi River Valley with the expansive lower alluvial valley. Several critical factors have been in operation since Cretaceous time to bring this about: (1) peneplanation of the Paleozoic rocks in pre-Cretaceous time, (2) downwarping of the Mississippi embayment and deposition of Cretaceous sediments extending far beyond the present limits of the upper Cretaceous, (3) uplift and erosion, (4) renewed sinking of the Mississippi trough and deposition of Eocene sediments, followed by regression of the sea during Oligocene, Miocene, and early Pliocene times, (5) uplift and prolonged erosion resulting in the development of the Lancaster peneplain of the upper Mississippi region and probably almost complete peneplanation of the weakly resistant Tertiary sediments of the Gulf embayment, (6) uplift and erosion producing the central Illinois partial peneplain including the Smithland surface, (7) uplift and erosion resulting in the Havana strath, (8) uplift and inner-valley cutting, (9) succession of glacial and interglacial stages of the Pleistocene epoch, (10) succession of thick loess deposits on the east valley wall, blown from the successive valley trains, (11) the Kankakee glacial river torrent enabling the Mississippi River to cut the Thebes gorge which it has since occupied, (12) the Lake Maumee glacial torrent causing the Ohio River to pour across the divide between the Cumberland and Tennessee Rivers, diverting the Ohio to its present course.

VERTICAL CHANGES IN CHEMICAL COMPOSITION OF A PARTIALLY WEATHERED ILLINOIAN TILL

R. K. Leininger, Haydn H. Murray, and Henrich Neumann
Indiana Geological Survey, Indiana University, Bloomington, Ind.; Indiana Geological Survey, Indiana University, Bloomington, Ind.; Mineralogisk-Geologisk Museum, Oslo, Norway

The high wall of an abandoned strip coal mine in Clay County, Indiana, has provided a section including 40 feet of Illinoian till. Sixty-five channel samples were obtained; each sample represented 6 inches of section. Tests with dilute HCl and color differences indicated three distinct zones: (a) lower—unleached and unoxidized; (b) middle—unleached and oxidized; (c) upper—leached and oxidized.

This paper deals with the results of chemical and spectrographic analyses of the minus 200-mesh material and of water solutions obtained with the fine fraction of each sample. A concurrent investigation of the vertical changes in mineral composition is the subject of another paper.

Preliminary qualitative analyses proved unsatisfactory in the study because of the apparent similarity of the samples. Quantitative data for pH, Li, Na, K, Rb, Be, Mg, Ca, Sr, Ba, B, Al, Y, Ti, Zr, V, Cr, Mn, Fe, Ni, Cu, Ga, C, Si, Pb, P, S, and F have shown some remarkable ranges of composition. For example, sulfur in the minus 200-mesh material increases from 0.3 per cent (as S) at the base to 0.6 per cent and decreases to 0.2 per cent in zone (a); it decreases further through zone (b) to a minimum of 0.005 per cent at the boundary of zones (b) and (c).

MANGANESE DIOXIDE FOR DRY CELLS

S. B. Levin, W. F. Nye, and H. Kedesdy
Signal Corps Engineering Laboratories, Fort Monmouth, N. J.

In the use of manganese dioxide for military dry cells the conflicting requirements of reactivity and stability place critical emphasis on crystallographic features. Within the relatively narrow composi-

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tional range permissible, the optimum combination of properties is closely related to phase type of MnO_2 as revealed by x-ray diffraction, and to crystallinity as revealed by the micro-morphology and the character of the diffraction pattern. The well-crystallized phases are insufficiently reactive; the almost-amorphous phase types are insufficiently stable in the presence of a fluid medium (the electrolyte) which facilitates ion transport. In polyphase manganese dioxide a minor phase, well crystallized and with acicular morphology, may adversely affect the stability of a major mesocrystalline phase by promoting recrystallization. In spite of difficulties of nomenclature, the distinction of phase types in terms of their crystallographic features is feasible and important. Examples of the important phase types will be illustrated.

REVIEW OF THE TECTOGENE CONCEPT

Chester R. Longwell
Yale University, New Haven, Conn.

The concept that an outer crustal layer is buckled sharply downward in the development of a mountain belt is open to question on several grounds. Kuenen's laboratory experiments assumed a definite outer layer, much stronger than the subcrust down to the surface of contact. Recent studies, including those of Tatel, Adams, and Tuve, cast serious doubts on the simple layering that is commonly assumed. A section through the Alps, published by Hess and republished with approval by others, is acceptable only on assumption of an outer sialic shell 50 km thick; this is not credible as applied to island arcs, which are regarded as growing mountain belts. A method of downbuckling without producing excessive depths of geosynclinal seas is hard to conceive.

Assumption of thickening in an outer shell by plastic deformation or by lateral transfer of low-density material leads to a more promising hypothesis. The operation of convection currents proposed by Griggs and others is one possible mechanism. Attempts to apply the tectogene concept to actual mountain belts suggest large variations in mechanism rather than a standard formula. The structural history of the Basin Range region and the Rocky Mountains has particular interest. Large-scale eastward transfer of sialic material at depth seems a plausible assumption to explain the profound changes in topography in accordance with the principle of isostasy. This concept is attractive as an explanation of the Colorado Plateau and similar great plateaus in other continents.

KATMAI SHORE LINES AND GLACIERS

John B. Lucke
University of Connecticut, Storrs, Conn.

The Shelikof Strait coast of Katmai National Monument shows two shore types—a rugged shore line of submergence, interrupted by flat valley trains between headlands. Two elevated wave-cut terraces stand at average elevations of 140 and 40 feet above mean high tide. The high terrace remnants extend along the entire (100 miles) coast from Katmai Bay to Cape Douglas. All have been glaciated at least once. Till up to 20 feet thick rests upon this terrace. The low terrace is best preserved at Kukak Bay and Cape Douglas but is nowhere so sharp nor so extensive as the high terrace.

Valley trains 4–8 miles wide form the shores of Katmai, Hallo, Kaguyak, and Swikshak bays. At the last two prograding has extended almost to the headlands. Compound recurved spits indicate a westerly littoral drift. Coastal bedrock is dominantly old volcanics with gentle dips, strong vertical joints, and dikes. At Katmai and Hallo bays volcanics grade into marine shale bearing Upper Jurassic invertebrates.

Alpine glaciers occupy large valley heads from Mt. Katmai to Cape Douglas, an 80-mile stretch. The largest extends to half a mile from the coast. All indicate recent retreat, yet glaciers once coalesced into Shelikof Strait covering headlands and outer islands (4 miles from shore) at least once. Present glaciers within 20 miles of Mt. Katmai are completely covered with the 1912 volcanic ash.

SANIDINE- AND ORTHOCLASE PERTHITES

W. S. MacKenzie and J. V. Smith
Geophysical Laboratory, 2801 Upton Street, Washington, D. C.

A new rapid x-ray method for determining accurately the reciprocal lattice angles α^* and γ^* of the soda phase of perthites has been developed. Using this method the lamellar structure of a number of sanidine- and orthoclase perthites has been investigated in detail. Measurements of the reciprocal lattice angles α^* and γ^* of the soda phase give results which indicate that the composition of this phase may be determined from these angles.

The orthoclase microperthites generally have a monoclinic potash phase and a soda phase corresponding to low-temperature albite or oligoclase. Specimens which have in addition a triclinic potash phase are found, and these have values of optic axial angle greater than would be expected from their bulk chemical composition.

Sanidine cryptoperthites have a monoclinic potash phase and a soda phase which is not pure high-temperature albite but has a considerable amount of orthoclase in solid solution.

No perthites have been found having a soda phase which gives evidence of states transitional between high- and low-temperature soda feldspar although such forms have been postulated by other workers for single-phase soda feldspar from both optical and x-ray studies.

STRATIGRAPHY OF EARLY TERTIARY VOLCANIC ROCKS IN SOUTHWESTERN UTAH

J. Hoover Mackin, Earl F. Cook, and Richard L. Threet
U. S. Geological Survey, University of Washington, Seattle, Wash.; University of Idaho, Moscow, Idaho; University of Nebraska, Lincoln, Nebr.

A sequence of early Tertiary volcanic rocks in southwestern Utah consists dominantly of ignimbrites. The ignimbrite units range from 30 to 700 feet in thickness and range from completely welded to nonwelded and from crystal to vitric types. All are in the rhyolite-latite-dacite compositional range. Interbedded lava flows and explosion breccias are andesitic.

Six ignimbrite units constituting the lower part of the sequence were spread over an essentially flat surface of Wasatch fluvial and lacustrine deposits. Several are continuous over an area of 1800 square miles with little change in thickness, degree of welding, or size of included fragments. The emplacement of laccolithic intrusions of monzonite porphyry eventually produced a dome-and-basin topography, which greatly restricted the spreading of the ignimbrite eruptions as sheetlike bodies. Vulcanism continued, but its surface expression became appreciably modified under these conditions.

Similar suites of early Tertiary volcanic rocks are represented throughout the Basin and Range and bordering provinces, but probably no single eruptive complex was continuous over more than a small fraction of this vast area. Each local complex is distinguished by its individual features rather than by conformity to a single pattern. However, the remarkable lateral extent of the ignimbrites in southwestern Utah indicates the possibility of working out the regional stratigraphy of these volcanics. The regional stratigraphic approach should provide an understanding of a unique type of vulcanism and a basis for cross-dating local episodes of intrusion, metallization, and deformation in the Cordillera.

STRATIGRAPHY AND PALEOECOLOGY, MT. HOPE MEMBER, CINCINNATIAN SERIES, OHIO-INDIANA-KENTUCKY

Thomas R. Magorian
111 Cassin Court, Alameda, Calif.

The Mt. Hope member of the Fairview formation, Maysville group, corresponds to the early evolution of *Platystrophia* in the Cincinnati area where it consists of as many as 100 cycles of alternating

limestone and shale. At the periphery of the outcrop area, *Platystrophia* first appears as an advanced type with fewer *Amplexopora*, *Plectorthis*, and limestone-shale cycles. Beds equivalent to those containing the earliest *Platystrophia* are included in the McMicken member, Eden shale. The extent of *Amplexopora*, *Hallopora*, and *Homotrypa* is selectively controlled by increased turbulence and silt to the southeast. Fossiliferous limestones and barren shales indicate epineritic deposition by wave action on an open shelf.

VON TRIGGER-CADIZ MUDFLOW OF JULY 1953

John F. Mann, Jr. and Richard O. Stone
University of Southern California, Los Angeles, Calif.

On July 14, 1953, a heavy rainstorm, centered near Lanfair Valley, about 40 miles northwest of Needles, California, resulted in a series of landslides in a small group of mountains just west of Von Trigger Spring. A desiccated mudflow resulting from these landslides was discovered about 2 weeks later. The mud flowed out of Lanfair Valley through the gap at Von Trigger Spring and was traced as follows: a mile north of Fenner in two washes; beneath three highway bridges just southwest of Essex; in three washes just northwest of Danby Station; across the Chubbuck Road a few miles south of Cadiz Station. The maximum distance between the observation points is about 45 miles. It is believed the mud reached Cadiz Dry Lake, indicating a total length on the order of 60 miles. It consisted entirely of mud and throughout its length was amazingly uniform both as to grain size and desiccated thickness, the latter usually less than 1 inch. The mudflow was destroyed by a flood on August 27–28, 1953.

SEA-WATER INTRUSION IN CALIFORNIA

E. C. Marliave
Sacramento, Calif.

Owing to heavy pumping, sea water has invaded 13 major coastal ground-water basins along California's coast and threatens many others.

Geologic study indicates that water-bearing deposits of Recent and Pleistocene age of the basins may be in direct contact with the ocean floor as free or confined aquifers, at relatively shallow depths. Establishment of a seaward hydraulic gradient near the coast or a physical barrier is necessary to safeguard the basins. Studies to date suggest the following methods of preventing intrusion: (1) raise water levels landward by reduction in extractions, controlling the pumping pattern or by spreading water, (2) create pumping trough along the coast, (3) establish ground-water ridge along coast by artificial recharge with fresh water, (4) create artificial barrier along coast.

Conclusions drawn from studies and laboratory experiments indicate that (1) sea water intrudes as a wedge inland in basal part of aquifer, (2) in a stable condition wedge extends inland a distance inversely proportional to rate of seaward fresh-water flow, (3) in repressurization by injection through wells, injection may be in any portion of aquifer, the quantity injected being the controlling factor, (4) injection on top of saline wedge may halt intrusion though landward portion of wedge will be cut off and may move inland, (5) unless inland demand for fresh water is reduced, injection must equal required seaward flow plus overdraft rate, (6) a physical barrier would be the most effective and may be economically feasible in certain instances.

DEVITRIFICATION IN PERLITE

Royal R. Marshall
California Institute of Technology, Pasadena, Calif.

Perlites from many localities scattered throughout the western United States have been studied in thin section. The microcrystalline phase of perlites may be divided into two parts. One phase, con-

sisting of crystallites and microlites, is characteristic of all hypohyaline rocks and apparently reflects the composition and cooling history of the magma. It may be considered primary. The other phase, which may be considered secondary, consists of devitrified films on both sides of the perlitic cracks which are commonly filled with a secondary mineral. The devitrification bordering the cracks typically is highly irregular in outline and diffusely birefringent. This phase appears to have developed in many cases after cooling of the perlite. Photomicrographs illustrate the greater abundance of this secondary phase in the older perlites among the specimens examined. Thus, in an Eocene perlite, the film of devitrification is 7 microns thick; in a Pliocene perlite, less than 1 micron thick.

To explain the transformation of the metastable glass phase into crystalline material, a mechanism involving the diffusion of water is introduced. Calculations indicate that the upper limit for the diffusion constant of water into natural glass in the neighborhood of 25°C is 10^{-6} cm²/M yr.

Hydrothermal alteration causes considerable variation in the penetration of devitrification inward from the numerous internal interfaces. This process and the presumed distribution of water in the perlites are correlated to explain the greater water content of the older perlites.

CaO-V_2O_5-H_2O SYSTEM

Richard Marvin
U. S. Geological Survey, Washington, D. C.

As an aid in determining environmental conditions of naturally occurring hydrous calcium vanadates, the CaO-V_2O_5-H_2O system was investigated. The variables of the system, in the order of their importance, are pH, temperature, and concentration. The pH values ranged from 0 to 12; temperature from 25° to 90° C; and the V_2O_5:CaO ratio from 0.5 to 10. The stability areas of eight crystalline phases were delineated. These phases can be divided into two major groups: the colorless phases, stable above pH 6.5; and the colored phases, stable below 6.5. According to the phase diagram, the stable phase below pH 2.2 at 25° C (pH 3.0 at 90° C) is hydrous vanadium pentoxide. Between pH 2.2 and 6.5 two naturally occurring minerals, hewettite and pascoite, are stable.

The stability field of pascoite is large at ordinary temperatures, gradually diminishes as the temperature rises, and disappears at about 70° C; at the same time the stability field of hewettite increases at the expense of the pascoite field. In the pH range from 6.5 to 7.5 and at temperatures less than 40° C, rossite is the stable phase. At higher temperatures several unnamed phases appear. At pH 7.5 to 10.0 two hydrous pyrovanadates(?) occur. Their stability range is influenced both by pH and by the V_2O_5:CaO ratio. Above pH 10, $Ca(OH)_2$ rapidly precipitates, and calcite forms if the solution is exposed to the atmosphere. Those phases whose stability field is near pH 7 seem to be the most soluble.

EXTRUDED MUDFLOW HILLS OF NIRASAKI, JAPAN

Arnold C. Mason and Helen L. Foster
University of Illinois, Urbana, Ill.; U. S. Geological Survey, Tokyo, Japan

The Nirasaki mudflow extends from the slopes of volcano Yatsuga-take southward approximately 20 km to the town of Nirasaki, Japan. The mudflow, consisting of andesite blocks and smaller fragments in a matrix of ash and dust, is broad on the open lower slopes of the volcano, but in its lower 9 km it is confined within a valley leading from the volcano and averages 2 km in width. Numerous isolated hills rise above the general surface of the mudflow, particularly in this lower part, where about 25 conical or curvilinear hills range from 10 to 60 m in height, 75 to 150 m in width, and 100 to 500 m in length.

The origin of the hills has been attributed variously to glacial deposition and to stream erosion. The authors propose that, under hydrostatic pressure of that part of the mudflow stream on the volcano's slopes, material of relatively low viscosity from the interior of the mudflow was extruded

through fractures in the drying, hardened crust. As part evidence, where the mudflow and one of these hills are together exposed in section, flow layers curve from horizontal in the mudflow mass to vertical where they extend upward into the overlying hill. The sizes and shapes of the hills reflect the quantity of extruded material and the form of the fracture.

RADIOACTIVITY OF SOME RECENT BOTTOM SAMPLES FROM LAKE PONTCHARTRAIN, LOUISIANA

John C. McCampbell
Department of Geology, Southwestern La. Inst., Lafayette, La.

An examination, by means of a scintillation detector and a scaling circuit, of some recent bottom samples taken from Lake Pontchartrain has been carried out under carefully controlled conditions. Considerable variation has been found in the disintegration rates. The data have been compared with both mechanical and chemical analyses of similar samples taken from the area, and a correlation has been made. The areas of finer textures show the higher counts, and the areas of low organic content likewise have higher counts than the areas of higher organic matter. The detrimental factors due to background count have been removed by heavy shielding and by the determination of the residual background before and after sample counting. To insure accuracy with such low counting rates, a counting time of 5 hours has been utilized.

EARLIEST WASATCHIAN VERTEBRATES FROM THE HIAWATHA MEMBER OF THE KNIGHT FORMATION, MOFFAT COUNTY, COLORADO

Malcolm C. McKenna
Department of Paleontology, University of California, Berkeley, Calif.

The earliest known fossil vertebrate assemblage from the Eocene Knight formation occurs in the Hiawatha member, stratigraphically below the Dad local fauna in Moffat County, Colorado. This assemblage has been named the Four Mile local fauna and has been collected by University of California field parties. Intensive washing techniques were employed in conjunction with the more usual collecting methods. Thus several thousand specimens have been recovered from deposits formerly believed to be nearly barren. The age of the Four Mile local fauna is approximately equivalent to that of the Sand Coulee fauna of the Willwood formation of the Bighorn Basin in northwestern Wyoming. Mammalian genera present include *Ectypodus, Neoliotomus, Plesiadapis, Tetonius, Palycodus, Phenacolemur, Cynodontomys, Entomolestes, Apheliscus, Diacodon, Didelphodus, Peratherium, Nyctitherium, Hyopsodus, Phenacodus, Hyracotherium,* and *Sinopa*. The Four Mile local fauna will provide a means for more detailed comparisons between the well-known early Eocene assemblages of northern Wyoming and New Mexico. New forms are present, and many previously known genera are represented by abundant specimens for the first time.

AREA-ALTITUDE GRAPH OF A MATURE DRAINAGE BASIN

Mark F. Meier
Calif. Institute of Tech., Pasadena, Calif.; Occidental College, Los Angeles, Calif.

Slope as a fundamental aspect of geomorphology must be considered in its three-dimensional setting—the drainage basin. One approach to understanding the form of these basins is the dimensionless area-altitude (or hypsometric) graph, which shows the relative amount of map area at different relative altitudes.

Measurements were made and graphs drawn of mature drainage basins on homogeneous rock in diverse areas from Arctic Alaska to Southern California. These data when combined with data published by Strahler showed that:

(1) Strahler's "hypsometric integral" can be replaced by the simpler parameter of mean height (expressed as a fraction of the total relief).

(2) Shape and mean height of the curves have little relation to size, shape, or slope of drainage basin, Horton's parameters, or climate.

(3) These curves closely approximate normal probability curves, except at the extreme "tails." The data appear as straight lines on probability graph paper, with mean heights symmetrically bunched around 50 per cent, and with relatively constant slope (standard deviation). Because mean height and other standard statistical terms can be read from these graphs, there is little need for Strahler's "model hypsometric function."

These last two conclusions suggest that understanding the characteristic shape of mature or equilibrium drainage basins in homogeneous rock is essentially a problem in geometry.

TOPOGRAPHY OF THE NORTHEASTERN PACIFIC SEA FLOOR

Henry W. Menard
U.S. Navy Electronics Laboratory, San Diego, Calif.

Dominant features of the northeastern Pacific sea floor are four great fracture zones—subparallel bands of grossly irregular topography which transect the whole area in a westerly direction. The zones approximate great circles and are uniformly spaced in a regular pattern. Zones average 60 miles in width, and each is at least 1400 miles long. Characteristic features of the topography are volcanoes, linear ridges, and seascarps, two of which are about 1 mile high and more than 1000 miles long.

Distinctive topographic provinces lie between fracture zones. For example, the Deep Plain, bounded by the Mendocino and Murray fracture zones, is a vast smooth plain, characteristically several hundred fathoms deeper than the remainder of the northeastern Pacific. Between the Murray and Clarion fracture zones and reaching from Baja California almost to the Hawaiian Islands is the Baja California Seamount Province which is very irregular in relief. Typically, large seamounts rise from a ridge and trough type of typography. Extensive smooth plains do not exist.

The distribution of smooth plains and irregular topography in the northeastern Pacific correlates with the accessibility to possible turbidity currents. Deep-sea channels, many with levees, have been traced across the areas with smooth plains. The topography suggests that turbidity currents are the dominant agents of deposition in areas from which they are not barred by trenches or ridges. Elsewhere, as in the Baja California Seamount Province, they are, at present, of far less importance.

REVIEW OF SILURIAN-DEVONIAN BOUNDARY RELATIONS IN THE GREAT BASIN*

Charles W. Merriam
U.S. Geological Survey, 346 Felton Drive, Menlo Park, Calif.

Lower Devonian faunas similar to those of the Helderberg Group, not previously reported from the Far West, occur in limestones locally overlying the Silurian Roberts Mountains formation of Merriam (1940) of the Monitor Range in central Nevada. In contrast Merriam's Roberts Mountains formation of the type area is overlain by barren dolomites to which he applied the name Lone Mountain (restricted). Whereas it is generally assumed that the Lone Mountain thus delimited is likewise of Silurian age, the meager fossil evidence so far obtained from these dolomitic facies is unconvincing.

In the Monitor Range, on the other hand, it is not improbable that the limestone in question, with its Helderberg-like fauna of Early Devonian age, represents a normal marine facies, equivalent to at least the upper part of the Lone Mountain dolomite. The Lone Mountain dolomite may thus be more or less transitional from Silurian to Lower Devonian.

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* Approved for publication by U.S. Geological Survey

The Early Devonian (Helderberg) age of the upper part of the Lone Mountain is likewise not incompatible with faunal evidence; this evidence indicates that a now widely recognized fossil zone near the boundary of the Lone Mountain dolomite and the lower Middle Devonian Nevada limestone is approximately Oriskany Early Devonian in age. Locally in the Great Basin this Early Devonian faunal zone of Oriskany age appears to fall within the upper part of a dolomite sequence corresponding to Lone Mountain dolomite.

PROBLEMS OF CONCRETE AGGREGATE IN THE LOS ANGELES AREA, CALIFORNIA

Richard Merriam
Geology Department, University of Southern California, Los Angeles, Calif.

Metropolitan Los Angeles, situated in large part on extensive alluvial fans derived from crystalline rocks of the San Gabriel Mountains, has long been well supplied with concrete aggregate. However, rapid growth of the cities has reduced reserves and covered potential source areas, including much of San Fernando and San Gabriel valleys, centers of present production. City and county zoning have imposed further limitations on land use. Studies are being made to provide guidance for future zoning as the best solution of the problem.

Production may be sustained by excavation below the water table, but several disadvantages will appear since the deeper material is generally coarser and less sound. Working under water will require changes in technique and equipment. Increased cost of operation will permit competition from imported aggregate, although most sources to the northwest and west of the Los Angeles area are undesirable because they contain reactive shale and chert.

Aggregate produced locally is of good quality in most respects. Occasionally material from parts of San Fernando Valley shows excessive reactivity with high-alkali cement because of opaline shales. Andesites and related volcanic rocks occur in the San Gabriel drainage but have not been troublesome. Sand from Pleistocene dunes of the Palos Verdes Hills shows reactivity when excavation has extended into and incorporated material from the underlying Miocene shale and diatomite.

ANALYSIS OF THE INTERACTION OF QUANTITATIVE VARIABLES IN A MODERN ENVIRONMENT OF SEDIMENTATION

Robert Lee Miller
Department of Geology, University of Chicago, Chicago, Ill.

Interaction of water temperature, pH, chlorinity, average sediment size, sorting, biological measurements, and certain other properties in contemporary sediments are investigated. Nonparametric correlation analysis of data collected at 55 stations in marine waters on east side of Louisiana delta indicate that pH measures form an intercorrelated group with measures of size and sorting of clastic sediments. A similarly highly intercorrelated group comprises water temperature at surface, at depth, and chlorinity at depth. These two groups are independent of each other. Current direction, current strength, skewness of sediment size distribution, abundance of Foraminifera, and variety of Foraminifera appear to vary independently of the other properties and of each other.

Certain highly correlated variables—*e.g.*, σ_ϕ, Md_ϕ, and species variety (excluding Foraminifera)—can be measured in both contemporary and consolidated sediments. Measurements of these properties may permit inference about nonmeasurable characteristics of ancient sediments. For example the pH of such an environment cannot be directly observed, but it shows strong negative correlation with sediment size and sorting, and strong positive correlation with species variety. These three properties can be measured in both modern and consolidated sediments. It may therefore be reasonably assumed that pH values can be inferred from values for σ_ϕ, Md_ϕ, and species variety in an analysis of consolidated sediment (lithology).

Further investigation must be made to determine whether the correlations remain stable or vary from one contemporary environment to another.

IGNEOUS PETROLOGY OF PARAGUAY*

Charles Milton and Edwin B. Eckel
U. S. Geological Survey, Washington 25, D. C.

From a collection of igneous rocks made by E. B. Eckel in southern and east-central Paraguay as representative of the principal rock types of the region, eight new analyses are given of granite, aplite, rhyolite, and quartz porphyry, two of basalt, and two of alkalic rocks—nepheline syenite and shonkinite. Each analysis is supplemented by spectrographic determination of 19 minor and trace elements. A widespread series of granitic, rhyolitic, and porphyritic rocks has been variously ascribed to ages ranging from Precambrian to Tertiary; however, all these rocks have a notably consistent petrographic character, chemical composition, and suite of trace elements, suggesting that all may be comagmatic and essentially contemporaneous. No known stratigraphic evidence opposes this suggestion. The presence of boulders of such rock in conglomerate of Permian age indicates Paleozoic or older age for these silicic rocks. Among basaltic rocks and diabase is one occurrence containing well-developed pseudobrookite. A heretofore unrecognized suite of alkalic rocks ranges from nepheline syenite to shonkinite; the latter contains an unusual type of kataphorite, similar to an amphibole previously known only from Wyoming and Western Australia.

The silicic rocks are presumably the southern extension of the Brazilian basement complex; the basaltic rocks are part of the vast Parana basalt of Triassic-Jurassic age of southeastern Brazil and eastern Paraguay; the alkalic rocks represent a group of magmas of relatively local extent but sporadically widespread; they may be younger than Precambrian.

NEW MINERALS, REEDMERGNERITE ($Na_2O \cdot B_2O_3 \cdot 6SiO_2$) AND EITELITE ($Na_2O \cdot MgO \cdot 2CO_2$), ASSOCIATED WITH LEUCOSPHENITE, SHORTITE, SEARLESITE, AND CROCIDOLITE IN THE GREEN RIVER FORMATION, UTAH*

Charles Milton, Joseph M. Axelrod, and Frank S. Grimaldi
U. S. Geological Survey, Washington 25, D. C.

Cores and cuttings from the Green River formation in Utah contain two new minerals, reedmergnerite and eitelite, with leucosphenite, searlesite, crocidolite, and shortite, in dolomitic shale. Reedmergnerite ($Na_2O \cdot B_2O_3 \cdot 6SiO_2$) occurs in many wells in Duchesne and Uintah counties as crystals rarely more than 1 mm long, colorless, triclinic, space group P1 or $P\bar{1}$ forms (100)(001)($\bar{1}02$)($\bar{1}01$) in one zone, and (010)(100) and ($\bar{2}10$) another; habit stubby prismatic; D = 2.69; indices of refraction: $\alpha = 1.560$, $\beta = 1.564$, and $\gamma = 1.572$. The name honors Frank S. Reed and John L. Mergner, technicians of the Geological Survey, whose skill has served petrological science for more than 40 years. Reedmergnerite and $Na_2O \cdot B_2O_3 \cdot 2SiO_2$ are the only known ternary phases of the system Na_2O-B_2O_3-SiO_2, and apparently both must form hydrothermally under relatively low temperature and pressure.

Searlesite ($Na_2O \cdot B_2O_3 \cdot 4SiO_2 \cdot 2H_2O$) occurs sparingly with eitelite, etc., the fourth reported occurrence and the first in Utah; however, J. J. Fahey, who described this mineral from Wyoming in 1950, also noted its presence in cores from the Green River formation in Utah in 1952.

Eitelite ($Na_2O \cdot MgO \cdot 2CO_2$) has been found only in the Carter Oil Company Kermit Poulson No. 1 around 2850 feet, in crystals a few millimeters in diameter. Indices of refraction: $\epsilon = 1.450$ and $\omega = 1.605$; good basal cleavage; agrees with hexagonal symmetry reported by Eitel and Skaliks, who synthesized it in 1929. This is the second of the alkali-alkali earth carbonates synthesized by Eitel and Skaliks that has been found in nature; the other is fairchildite, $K_2O \cdot CaO \cdot 2CO_2$.

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* Publication authorized by the Director, U. S. Geological Survey

Eitelite is named to honor Wilhelm Eitel, Director, Institute of Silicate Research, University of Toledo, Ohio.

ZONED PLAGIOCLASE IN METAMORPHIC ROCKS

Peter Misch
Department of Geology, University of Washington, Seattle, Wash.

Since metamorphic plagioclase is often stated to lack normal, and especially recurrent, zoning, and since the presence of such zoning in a granitic rock is widely accepted as proof of an igneous origin, the plagioclase was examined in many varied, nongranitic, and unquestionably metamorphic rocks from different areas. Zoning, though on the whole less common than in certain igneous rocks, is widely present, with normal more frequent than reverse zoning. Recurrent zoning was also observed, for instance in mica schist and calc-silicate granulite. Zoning ranges from highly gradational to rather sharp, and from anhedral to euhedral. A low metamorphic grade, as well as strong syncrystalline deformation, are unfavorable for zoning. Petrographic features suggest different causes of zoning: (1) Thermal control may produce normal, reverse, or recurrent zoning in rocks containing "anorthite substitutes" (epidote, zoisite, calcite plus mica, Ca scapolite, etc.), the ability of the plagioclase to incorporate anorthite molecule changing with the temperature, and a supply of potential anorthite being available. (2) Slow, very small-scale diffusion of Ca from more into less calcareous bands in higher-grade rocks may cause reverse zoning. (3) Introduction of Na may produce normal zoning. (4) Contrasted to these cases of growth zoning, passive or secondary normal zoning may occur if plagioclase is partially replaced by (a) Ca-rich minerals (epidote, hornblende), or (b) K feldspar; preservation of the original plagioclase lattice in the more sodic secondary rims indicates microscopic lattice diffusion. In other cases, the causes of zoning remain obscure.

ORIGIN OF CALCAREOUS OÖLITHS

P. H. Monaghan and Melba L. Lytle
Humble Oil & Refining Co., Houston, Texas

Laboratory studies were undertaken to discover mechanisms which might explain the origin of calcareous oöliths.

Calcium carbonate was precipitated from sea water by evaporation, by addition of precipitating agents, and by the growth of sulfate-reducing bacteria.

The effect of the major ions in sea water on the form of the calcium carbonate precipitate was studied.

From these studies the following conclusions may be drawn:

(1) Calcareous oöliths or spherulites can be chemically precipitated from sea water if the carbonate ion concentration at the time of precipitation is greater than 0.002 mol per liter. This is a higher concentration than is found in normal sea water.

(2) Calcareous oöliths may also be formed through the growth of sulfate-reducing bacteria in sea waters.

(3) The presence of the magnesium ion in sea water causes calcium carbonate to precipitate as aragonite rather than calcite.

(4) The laboratory conditions necessary for the chemical precipitation of calcareous oöliths might be reproduced by an environment in which fresh waters high in carbonate ion flow into a shallow sea. Such a mechanism does not appear to be responsible for any large present-day deposits.

(5) Environments where sulfate-reducing bacteria might be important in the origin of calcareous oöliths should be characterized by deficiency of oxygen, increased pH, and presence of hydrogen sulfide or sulfide salts. Such environments might be highly localized.

EFFECT OF LOCAL GEOLOGY AND SOIL CONDITIONS ON INTENSITY OF GROUND MOTION IN SOUTHERN CALIFORNIA EARTHQUAKES

Donald F. Moran and Karl V. Steinbrugge
Pacific Fire Rating Bureau, 548 South Spring Street, Los Angeles, Calif.

Experience in severe earthquakes has indicated that damage to structures is usually intensified by poor soil conditions, such as man-made fills and water-saturated natural alluvium. Until recently, most local building codes required an increase in the lateral force factor for structures in poor soil areas. The present trend, though without apparent basis in fact, is to disregard soil differences.

Earthquake insurance rates are increased for buildings located on filled or poor natural ground, and detailed maps have been prepared to show the distribution of these areas in Los Angeles, San Francisco, and Portland.

Damage data have permitted positive correlation between intensity of ground motion and foundation conditions where those conditions varied markedly within heavily populated areas, as in San Francisco (1906) and Tokyo (1923). Such positive evidence generally could not be obtained from past earthquakes in southern California. However, the coastal regions of Terminal Island, Long Beach, Seal Beach, and San Diego, which have developed rapidly in recent years, should produce valuable data in future shocks.

In earthquake-damage surveys, the basic difficulty will continue to be the problem of locating comparable structures on different types of soil and preferably close together.

PROPOSED TYPE SECTIONS FOR THE QUEEN AND GRAYBURG FORMATIONS OF GUADALUPIAN AGE IN THE GUADALUPE MOUNTAINS, EDDY COUNTY, NEW MEXICO

William R. Moran
Union Oil Company of California, 617 West 7th Street, Los Angeles, Calif.

The "Queen sand" was named "from extensive outcrops in the vicinity of Queen Post Office" in Eddy County, New Mexico (Crandall, 1929), but no type section was designated, and no thickness was given. The "Grayburg formation" was named by Dickey (1940) from an interval in a well drilled 1 mile north of the Grayburg pool in Eddy County. He stated, "The . . . Grayburg undoubtedly crop(s) out in the Guadalupe Mountain area west of Carlsbad, and at some future time (it) should be measured and defined in this area." Recent mapping has shown that both units deserve formational status. Since a great deal of confusion has arisen because these two commonly used names have never been adequately defined in their surface outcrops, type sections are herewith proposed.

The suggested type section for the Queen formation is 5 miles S. 75° E. from the site of the Queen Post office on the west wall of Dark Canyon, in the SW¼ of Sec. 36, T. 24 S., R. 22 E., where 421 feet of alternating sandstone and sandy dolomite is exposed. Here the Queen underlies the Seven Rivers formation and overlies the Grayburg. The Shattuck member of the Queen formation proposed by Newell (1953) has been recognized as the uppermost 100 feet of this section.

The proposed surface type section of the Grayburg formation is on a spur and in an unnamed canyon above Sitting Bull Spring, in the NE¼ of Sec. 9, T. 24 S., R. 22 E., where a total thickness of 475 feet of alternating sandstone and dolomites is exposed.

STRUCTURE OF A PORTION OF THE EASTERNMOST GARLOCK FAULT ZONE, SAN BERNARDINO COUNTY, CALIFORNIA

William R. Muehlberger
Department of Geology, The University of Texas, Austin, Texas

The portion of the Garlock fault studied lies along the southern flank of the Quail Mountains in northern San Bernardino County, California.

The pre-Tertiary rocks in this region are acidic intrusive rocks of Archean and late Jurassic age. A small area of Paleozoic (?) metasediments and meta-andesite crops out in the northwestern portion of the range. The late (?) Tertiary-Quaternary sequence is rhyolite, andesite, latite, basalt (listed in order of extrusion), with interbedded tuffs and fanglomerates.

The Garlock fault zone is at least 1½ miles wide and consists of a series of subparallel breaks with associated fault scarps and belts of crushed rock. The crystalline rocks in the zone have been crushed to angular fragments, 1–2 inches in diameter, set in a matrix of pulverized material. The crushing has been nonuniform in that some zones of the rock are only slightly brecciated while others are nearly pulverized.

Movement along the Garlock fault is believed to be principally left-hand strike-slip. Streams have been offset as much as 2000 feet, whereas slices of distinctive portions of the Cenozoic strata have been offset as much as 1½ miles. The latter figure represents the maximum demonstrable displacement. Warping of older strata, offset erosion surfaces, and alluvial scarplets indicate the Quail Mountains along the north side of the Garlock fault have risen relative to the south side. Minor grabens are formed by back-facing alluvial scarplets.

VERTICAL CHANGES IN MINERAL COMPOSITION OF A PARTIALLY WEATHERED ILLINOIAN TILL

Haydn H. Murray, Richard K. Leininger, and Henrich Neumann
Indiana University, Indiana Geological Survey, Bloomington, Ind.; Indiana Geological Survey, Bloomington, Ind.; Mineralogisk-Geologisk Museum, Oslo, Norway

This study gives the vertical changes in mineral composition of a partially weathered Illinoian till section described in a paper by the same authors concerning the vertical changes in chemical composition. The minerals were identified using the petrographic microscope, x-ray diffraction, and differential thermal analysis. The minerals in the minus 20 to plus 200-mesh range were examined in about 20 samples, but the major work was done on the minus 200-mesh fractions of 65 samples.

The minus 200-mesh fractions in the lower, unoxidized, unleached zone (assumed to be unaltered till) contain mostly quartz, calcite, dolomite, feldspar, kaolinite, illite, chlorite, and a small amount of montmorillonite. The same fractions in the middle, oxidized, unleached zone contain the same minerals; however, the crystallinity of the clay minerals, illite and chlorite, decreases, presumably because of oxidation of iron, and the amount of montmorillonite increases slightly. In the minus 200-mesh fractions of the upper, oxidized, leached zone, primary calcite and dolomite disappear; kaolinite, illite, and chlorite either disappear or are present in very small amounts. The amount of montmorillonite increases markedly in the upper, highly weathered zone; this fact is contrary to expectations because kaolinite is usually considered the most stable clay mineral. Organic material is present in the unoxidized zone but almost disappears in the oxidized zones.

STRUCTURAL SCHEME OF SEPIOLITE

Bartholomew Nagy and W. F. Bradley
Pennsylvania State University, State College, Pa.; Illinois State Geological Survey, Urbana, Ill.

An idealized structural scheme for sepiolite is deduced from the observed x-ray diffraction effects in the zero layer line of diagrams obtained from several natural fibers. The structure consists of a centered array of linked chains of composition $H_6Mg_8Si_{12}O_{30}(OH)_{10} + Aq$, somewhat similar to those found in attapulgite; the chains enclose a second centered array of channels in which molecular water is disposed.

The hk0 projection is orthogonal with a = 13.4A and b = 27A. The skeletal chains are centered about 0, 0, Z and ½, ½, Z. Mg sites for each chain are at x = 0 and y = 0, $\pm 1/18$, $\pm 3/18$, $\pm 3/18$,

and $\pm\frac{1}{18}$. Oxygen and hydroxyl, silicon, and oxygen, in layers, fill out each chain co-ordinated as in a mica or a chlorite, and the eight oxygens at $\frac{1}{4}$, $\frac{1}{4}$, Z are each links common to two chains. The water channels are centered about $\frac{1}{2}$, 0, Z, and 0, $\frac{1}{2}$, Z.

The disposition of the eight octahedral ions (mainly Mg) indicated by chemical analysis among the nine positions available in the schematic chain is not specified.

The quality of agreement between calculated and observed hk0 type intensities is illustrated. It is considered to confirm adequately the idealized section. Probably the entire structure is in C 2/m.

ORIGIN OF SAND AND SILT ALTERNATIONS (DISCONTINUOUS GRADED BEDDINGS)

Noriyuki Nasu
Scripps Institution of Oceanography, University of California, La Jolla, Calif.; Geological Institute, University of Tokyo

There have been many discussions of the occurrence of thin-bedded alternations of sand and silt layers, and special emphasis has been given to abrupt change in texture at the base of graded beds. However, in many formations relatively abrupt changes also exist in the transition from coarse to fine sediments in a single unit. An interpretation of the abruptness of textural changes within a bedding unit is made here from hydrodynamic considerations, using examples from the Pliocene marine Miura formation of Japan. Because of basic differences in settling velocity and critical tractive velocity, source sediments are sorted into sand and silt fractions during transportation, and upon deposition this will tend to cause a relatively sharp transition between sand and silt. In addition to this vertical transition, sand and silt will also tend to show rapid transition zones in a horizontal direction. Sporadic changes in the amount of source material and competency of the transporting agent will result in rapid horizontal migration of the transition zone between sand and silt, and in this way certain submarine areas would be covered by sheets of sand and silt alternately, so that the resulting formation would exhibit both horizontal and vertical transitions.

CHARACTERISTICS OF HIGH-POLAR TYPE GLACIERS IN NORTHWESTERN GREENLAND

Laurence H. Nobles
Department of Geology, Northwestern University, Evanston, Ill.

In northwestern Greenland the outer 40 to 60 miles of the ice cap is a highland ice cap composed of a relatively thin ice carapace resting on a very rugged subice topography. The border of the ice cap in this region is composed of three types of features: (1) large, heavily crevassed outlet glaciers, moving a few feet per day, and draining large portions of the cap; (2) smaller valley glaciers, draining relatively restricted accumulation basins, that may be deteriorating rapidly; (3) uncrevassed ramp areas, moving only a few inches per day.

All this ice is of high-polar type, in which negative temperatures prevail throughout most of the year in all but the upper few feet. At a depth of 8 meters the ice temperature is constant throughout the year at −14°C. In marginal regions the upper 2–3 feet of ice is at 0°C. by the end of the melt season. Thus the temperature regimen of this high-polar ice is strictly analogous to that of perennially frozen ground. All runoff is on the surface, forming such surface features as slush avalanches, algal pits, and an integrated drainage pattern. Debris content of the ice is relatively small.

Net accumulations as high as 25 inches of water have been recorded at elevations of 4000 feet, 30 miles from the border of the ice cap. Accumulation is less both in the interior and closer to the margin. Ablation of 20–25 inches of water during the melt season is common in marginal regions. The regional firn line is about 3000 feet.

ARCHAEOCYATHID LOCALITIES IN BRITISH COLUMBIA

Vladimir J. Okulitch
Division of Geology, The University of British Columbia, Vancouver, B. C.

Archaeocyatha (Pleospongia) are known from six localities in eastern and northern British Columbia. The localities outline the approximate western shore line of the Lower Cambrian geosyncline. The Archaeocyatha have not been found in the eastern portion of the sea.

The geographical position of the localities and the faunal lists from each are given in the paper. The localities are (1) McDame Creek, near headwaters of French River, a tributary to Dease River, northern British Columbia, Lat. N.59°20′, Long. 129°25′W; (2) Aiken Lake area, valley of the Osilinka River, at Lat. N.56°09′, Long. 125°07′W; (3) Sinclair Mills, southwest bank of Fraser River, about 4 miles upstream from Sinclair Mills, Rocky Mountain Trench; (4) Quesnel Lake area, Turk's Nose Mountain, at the bend of Cariboo River, between Sandy Lake and Spectacles Lake; (5) east side of Dogtooth Mountains, Purcell Range, rims of Canyon Creek, and Holt Creek; and (6) Salmo River area, near the crossing of the International Boundary by the South Fork of the Salmo River, Lat. N.49°00′ to N.49°04′, Long. 117°08′ to 117°05′W.

SIZE-FREQUENCY DISTRIBUTIONS OF EXTINCT SPECIES OF ANIMALS AND THEIR BIOLOGICAL POPULATIONS

Everett C. Olson
Department of Geology, Univ. of Chicago, Chicago, Ill.

Visual analysis of size-frequency distributions of samples of about 200 extinct species of animals show: 70 per cent bell-shaped; 15 per cent polymodal; 10 per cent skewed; 5 per cent highly irregular; 95 per cent fail to include the full size range of the species. Most distributions are inadequate for statistical estimation of the original biological population.

Samples of fossils have been drawn from: (1) the fossil assemblage, or (2) the death assemblage of the biological population (UB). Knowledge of size-frequency distribution of UB must come from sources independent of size-frequency distribution of the sample. From growth and mortality rates (relative to maximum life span), the form of the theoretical size-frequency distribution of the death assemblage can be approximated. Mortality rate can be expressed as a time-frequency distribution in per cent, per time interval. The mean growth curve and variance provide a basis for a theoretical time-size distribution. Combination of the two distributions provides a theoretical size-frequency distribution of UB.

A graphic solution, involving simplifying assumptions, is sufficient for estimation of total bias in samples. Eight theoretical size-frequency distributions, involving various combinations of growth curves and rates of growth and mortality, cover most cases.

About 0.5 per cent of the samples studied approximate the form of the appropriate distribution. Many represent equivalent parts of their universes, UB. Modifications of the concept of UB, to include only some meaningful part of the whole, allows valid inference to this restricted universe.

WOLFCAMPIAN REEFS OF THE NORTHERN SACRAMENTO MOUNTAINS, OTERO COUNTY, NEW MEXICO

Carel Otte, Jr.
Pure Oil Co., Res. and Devel. Labs., Crystal Lake, Ill.

Northeast of Tularosa, in south-central New Mexico, a uniformly 60-foot thick limestone ledge forms the crest of the low frontal escarpment of the northernmost Sacramento Mountains. This unit consists essentially of two parts: a number of lenticular structures of massive accretionary

limestone forms the lower part, and the upper part consists of bedded, coarse, detrital limestone. The entire unit grades laterally into calcareous shales approximately 8 feet thick. Fusulinids associated with these strata are of early Wolfcampian age.

The height of the structures varies considerably and averages 40 feet. The flanks dip locally as much as 35°. A filamentous type alga probably formed the main cementing agent for the fine-grained sediments in these structures. Skeletal remains of brachiopods, crinoids, and fusulinids occur largely in small pockets. The terrigenous clastics content averages 1.7 per cent and suggests development into the zone of water agitation. The absence of rough water deposits indicates growth not far above wave base. The structures probably grew above the level of adjacent contemporaneous sedimentation and are considered reefs. Influx of large amounts of fine terrigenous clastics probably terminated reef growth.

The upper member is composed of fragments of tubular algae, crinoids, brachiopods, and fusulinids and is considered a post-reef deposit. The reef structures probably affected marine life and sedimentation in post-reef time, thereby localizing the formation of the detrital limestone.

The reefs developed in a zone about a third of a mile wide and about 3 miles long, parallel to an early Permian landmass to the east.

MANGANESE CONTENT OF GARNETS FROM THE FRANCISCAN SCHISTS

A. Pabst
Department of Geological Sciences, University of California, Berkeley, Calif.

Many years ago Pabst described *The garnets in the glaucophane schists of California* (*Am. Mineralogist* 16: 327–333, 1931) reporting a very low manganese content. In summarizing the range of the spessartite content was given as "0–1%".

Several years ago, at the suggestion of Dr. Max D. Crittenden, some of these garnets were reexamined. New determinations indicated that the 1931 report of manganese content was seriously in error.

Nearly 2 years ago, in response to an inquiry, the writer informed Doctor Schürmann of the Hague of this error and indicated the correction. In spite of this Doctor Schürmann (*Neues Jahrb. f. Min.*, 85: 303–394, 1953) has recently cited my old erroneous figures without comment.

Recently a full analysis of a garnet from eclogite associated with glaucophane schist near Healdsburg, California, has been reported by Dr. Iris Borg. This also shows a more than negligible amount of MnO.

Thanks to the courtesy of Doctors Borg and Crittenden it is now possible to make the corrected statement in the following table:

Garnet	MnO	S. G.	N_{Na}	a_0
	wt.			
Hilton Gulch, Santa Clara Co., Calif. "A" of Pabst, 1931	2.03%	3.95 ± 0.04	1.795 ± 0.002	11.62 ± 0.01Å
South of Calaveras Valley, Santa Clara Co., Calif. Crittenden, 1951	4.63	4.00 ± 0.05	1.795 ± 0.002	11.61 ± 0.01
Near Junction School, Healdsburg Quad., Calif. Borg, 1954	0.92	4.08 ± 0.02	1.795 ± 0.003	11.62 ± 0.01

The last column of table III in Pabst (1931) should be revised to read "range of grossularite 8–30%, andradite 4–24%, almandite 48–56%, pyrope 16–20%, spessartite 1–10%". The order remains as before even though the spessartite limit is raised by a factor of 10.

PETROLOGY OF SPODUMENE-BEARING PEGMATITES

Lincoln R. Page
U. S. Geological Survey, Denver Federal Center, Denver, Colo.

The wide variety of petrologic types of spodumene-bearing pegmatites is the result of differences in the initial composition of magmas, mode of emplacement, crystallization history, and simultaneous deformation of the wall rocks. An individual body may have formed by cooling of single or multiple masses of magma, with or without metasomatic replacement. Each body is composed of at least two distinct mineralogic and structural units; some bodies are composed of as many as 13 units. Spodumene-perthite, spodumene-perthite-amblygonite-albite-quartz, spodumene-albite-quartz, and spodumene-quartz are the most common mineral assemblages in lithium-rich units. The long axes of spodumene crystals—either fresh or altered—may be oriented parallel or at right angles to the wall-rock contacts, at right angles to the zonal contacts, parallel to pre-existing gneissoid banding, or at random.

Spodumene is commonly the first mineral to form in the pegmatite unit and acts as a locus for crystallization of albite. The early-formed spodumene crystals may react completely with rest liquids to yield pseudomorphs composed of clay, mica, and other minerals; less complete reaction commonly results in corroded and rounded crystals.

Flow structures, broken crystals, and deformed wall rocks indicate forceful intrusion of initial viscous lithium-bearing magmas; other orientations of spodumene within the units are the result of crystallization during regional deformation or under static conditions. Replacement units rich in spodumene form as the result of abrupt changes in physical conditions during crystallization.

PENNSYLVANIAN REPTILES OF KANSAS

Frank E. Peabody
Department of Zoology, University of Kansas, Lawrence, Kans.

New, topotypic specimens of *Petrolacosaurus* Lane obtained in 1953 and 1954 consist of the better part of nine skeletons, including skulls, in varying degree of disarticulation and completeness. Inaccuracies of an earlier reconstruction may now be corrected—*e.g.*, the isolated pelvis originally referred to the type by Lane is that of another reptile and markedly different from the petrolacosaur pelvis. Peabody's conclusion in 1952 concerning the relationships of *Petrolacosaurus* is essentially correct—the reptile is a very primitive diapsid with a pattern of temporal fenestration resembling the much younger *Pricea* Broom of South Africa.

Associated with the petrolacosaurs are two reptiles, probably pelycosaurs, slightly larger and represented by part of one skeleton and other isolated bones all significantly different from the petrolacosaur.

Reptile bones are distributed through the middle 3 feet of the Rock Lake shale member of the Stanton formation northwest of Garnett and through 1000 feet of outcrop. Numerous trackways of small to large tetrapods and shrinkage cracks indicate frequent subaerial exposure of part of the marginal lagoon in which the reptiles were preserved along with coelacanth fish, terrestrial plants and arthropods, and marine invertebrates.

Possibly five different environments are represented by fossils of the petrolacosaur beds: (1) brackish lagoon; (2) subaerially exposed parts of the lagoon; (3) offshore, clear, marine water; (4) fresh-water stream flowing into the lagoon; (5) marginal, coastal land with flora dominated by gymnosperms.

BRIEF REVIEW OF QUATERNARY EVENTS IN ALASKA

Troy L. Péwé
U. S. Geological Survey, College, Alaska

More than one major pre-Wisconsin glaciation is recognized in the Aleutian Range, Kenai Peninsula, Alaska Range, Seward Peninsula, and the Brooks Range. The greatest glacial advances were

along the south and southeast coast, where huge ice sheets pushed out to sea. About 20 per cent of Seward Peninsula was glaciated; in the interior of Alaska the glaciers were small. Rivers were alluviated, and loess was extensively deposited in the interior. Extreme modification and dissection of pre-Wisconsin deposits suggest a long time interval between deposition of pre-Wisconsin drift and later Wisconsin moraines. Permafrost disappeared in central Alaska during this interval.

Two major Wisconsin glacial advances are recognized in the Aleutian Range, Kilbuck Mountains, Kenai Peninsula, southeastern Alaska, Chugach Range, Seward Peninsula, Brooks Range, and at four places in the Alaska Range. The latest major glaciation was about 10,000 to 12,000 years ago (radiocarbon). Less extensive later glaciations are also recorded. In relatively ice-free central Alaska two prominent loess blankets and associated vertebrate-bearing muck deposits were formed in Wisconsin time. The periods of major loess deposition are separated by a warm period, when permafrost was much less extensive than today.

A warm interval about 3500 to 5000 years ago (radiocarbon) is recorded by slight thawing of permafrost in central and northern Alaska and great glacier retreat throughout the Territory but mainly in southeastern Alaska. This warm interval was followed by prominent glacial advances of recent centuries throughout Alaska and renewal of permafrost in central and northern Alaska.

SOME PROPERTIES OF VECTOR AND ARITHMETIC MEANS OF ANGLES, WITH GEOLOGIC APPLICATIONS

Howard J. Pincus
The Ohio State University, Columbus, Ohio

In analyzing collections of measurements of dips, azimuths, dihedral angles, and other geologic orientation data, the calculation and interpretation of average or mean values are usually important steps. The choice of a type of mean may be difficult, and indiscriminate calculation may yield inconsistent results.

These problems are treated here by investigating properties of two commonly used averages, with geologic illustrations.

The effects of extreme values on arithmetic and vector means are examined in detail for two-dimensional (univariate) data. Unlike the arithmetic mean, the vector mean is sensitive to dispersion; this must be considered in treating some commonly used geologic data.

The dependence of vector mean angles on dispersion and on the deviation of the extreme value is derived; this function is plotted as a contoured surface in three dimensions. The topological relationship between arithmetic and vector means is shown on this surface, as are the boundaries within which the two are roughly equivalent; applications are shown.

The sum of cosines of angle deviations about the vector mean is a maximum; this property helps to standardize computations.

A simple computational scheme for evaluating the angle and strength of the vector mean is illustrated; numerical work is surprisingly light.

Vector and arithmetic means are presented for angle data from diverse fields. These means are used in fitting linear and circular normal distributions to the data. Checking goodness-of-fit with chi-square, the linear distribution fares better than expected.

SURVEY OF THE ORDOVICIAN EDRIOASTERS OF THE CINCINNATI AREA

Jesse B. Pogue
Shell Development Company, 3737 Bellaire Blvd., Houston, Texas

A survey of 586 specifically identifiable Cincinnatian edrioasters from the University of Cincinnati Museum collections indicates the possibility of erecting a new order to include two families, the Agelacrinitidae and the Hemicystitidae, and the genera *Carneyella, Cincinnatidiscus, Cystaster,*

Hemicystites, *Streptaster*, and *Isorophus*. This new group is characterized by a lack of thecal plates across the aboral surface, a distinct system of peripheral plates, and the absence of thecal and ambulacral pores.

A summary of the work of Bather, Foerste, Williams, and others in the morphology, physiology, and ontogeny of the Edrioasteroidea has been supplemented by observations and illustrations of Williams' Lawshe, Ohio, material and exceptionally well-preserved specimens from the University of Cincinnati Museum collections not previously studied. A restoration of the digestive system has been proposed as well as a possible method of noncemented semipermanent fixation.

Hall's holotypes of *Cystaster* and *Streptaster* from the Museum of Comparative Zoology, Cambridge, Massachusetts, are photographically reproduced for the first time.

MULTIVARIATE ASPECTS OF BASAL PENNSYLVANIAN ORTHOQUARTZITE SOURCE-AREA STUDIES OF NORTH-CENTRAL UNITED STATES*

Paul Edwin Potter
Illinois Geological Survey, Urbana, Ill.

Regional sediment source-area studies generally utilize a combination of genetically interrelated variables to define mineral associations and establish sediment sources. Multivariate analysis makes possible a simultaneous evaluation of such variables. Feldspar abundance, metamorphic quartz abundance, and zircon roundness are used in a multivariate evaluation of regional mineral associations of the basal Pennsylvanian orthoquartzites of the Eastern Interior, Michigan, and portions of the Appalachian Basins.

The experience of this study suggests that provenance sampling design entails three broad aspects: (1) the intensive study of a combination of variables in a relatively small to moderate number of samples; (2) the use of multivariate analysis to test geological hypotheses formulated from independent criteria, such as areas with different or like flow patterns, geographically distinct areas, or areas belonging to different facies of sedimentation; (3) using the most discriminatory and/or least expensive variable, petrologic mapping in contiguous areas for the more precise determination of mineral-association boundaries.

DESMOINESIAN FACIES OF THE SACRAMENTO MOUNTAINS, NEW MEXICO

Lloyd C. Pray and Roy W. Graves, Jr.
California Institute of Technology, Pasadena, Calif.; California Research Corporation, P. O. Box 446, La Habra, Calif.

Two major sedimentary facies of Desmoinesian (Pennsylvanian) age are exposed in the Sacramento Mountains in south-central New Mexico. A deltaic facies about 4 miles wide and 1000 feet thick occurs in the northern part of the mountains and grades abruptly northeast and south into an equivalent thickness of shelf limestone. Although repeated fluctuations in sea level and at least some temporary emergence of the area of deltaic deposition occurred, the areal position of these two facies was essentially constant throughout Desmoinesian time.

The shelf-limestone facies is regionally the more extensive. It was deposited in shallow, normal marine waters and consists of light-gray, thick-bedded to massive calcilutites with minor amounts of darker, thin-bedded argillaceous limestones, coquinoid limestones, and calcarenites. Chert occurs sporadically. Fossils, only locally abundant, are principally brachiopods, corals, crinoids, bryozoans, calcareous algae, and Foraminifera.

The deltaic facies was deposited in a shallow, predominantly marine environment and consists of interbedded shales, siltstones, sandstones, and minor limestones. Shales are typically calcareous; some contain abundant plant fragments. Drab-colored, calcareous siltstones and subgraywackes are

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common. The coarse clastics range from quartz-rich sandstones and fine conglomerates to fossiliferous calcarenites and calcirudites. Calcilutites are dark and argillaceous, and some are partly silicified. The limestones of this facies are more fossiliferous than the shelf limestones, but, with minor exceptions, the two facies have similar fossil assemblages. The terrigenous clastics, derived principally from Precambrian rocks, are believed to have been introduced from the east.

CORRELATION OF THE ABO FORMATION OF SOUTH-CENTRAL NEW MEXICO

Lloyd C. Pray and Carel Otte, Jr.
California Institute of Technology, Pasadena, Calif.; Pure Oil Company Research Laboratory, Crystal Lake, Ill.

Field investigations have clarified the relationship of the terrestrial Abo formation with other lower Permian formations in south-central New Mexico and west Texas. The Abo is transitional with underlying latest early Wolfcampian marine strata (Bursum formation) in the northernmost Sacramento Mountains, where deposition was essentially continuous from Pennsylvanian into middle Permian time. Southward to beyond the Hueco Mountains, early Wolfcampian strata are absent, and Abo or equivalent marine strata of later Wolfcampian age unconformably overlie Pennsylvanian and older rocks.

The Abo, 1400 feet thick in the northernmost Sacramento Mountains, thins abruptly to 250 feet in the central Sacramento Mountains. It extends southward as two major tongues of red beds separated by, but transitional with, a southward-thickening sequence of brackish to marine carbonates, fine clastics, and minor gypsum of the Hueco formation. The basal tongue of the Abo correlates with the Powwow conglomerate, and the upper tongue (considered the entire Abo by Darton) forms the Deer Mountain red shale in the Hueco formation. The Abo of the Sacramento Mountains is the lateral equivalent of the lower 1200 feet of the Hueco formation at Hueco Canyon, Texas, and probably correlates with both the Abo (Leonardian) and Hueco (Wolfcampian) as identified in the Permian Basin subsurface. At least 100 square miles indicated as Magdalena formation (Pennsylvanian) on the State and United States geologic maps between the Sacramento and Hueco Mountains are Abo-equivalent marine Permian strata.

Lowermost Yeso strata (Leonardian) change rapidly northward from limestone in the Hueco Mountains to gypsum.

NONMARINE NATURE OF QUATERNARY ATLANTIC AND GULF COASTAL PLAIN OF SOUTHEASTERN NORTH AMERICA

W. Armstrong Price
Texas A & M College, College Station, Texas

Official reports (Texas, Louisiana, Mississippi) and Price's work show supposed "emerged marine bottoms" actually covered continuously by subaerial deltaic deposits, with 10-mile-wide belts of *strand* and *lagoon* deposits between deltaic salients, around Gulf between Yucatan and Florida except for volcanic areas.

The literature and map and photograph studies (Price) now throw burden of proof on "marine-bottom" advocates to find exposed marine surfaces or deposits on Atlantic, except on open bays. Recognition of Pleistocene barrier islands enclosing lagoon plains (Price, 1933) from Florida to South Carolina (Cooke, 1936, 1943; MacNeil, 1950) here extended to New Jersey shows continuous strand-lagoon plains at least 10 to 60 miles wide between latitudes of Miami and Philadelphia and from contemporary shore line to Suffolk and probably Surry scarp. These "terraces" seem to expose only *lagoonal*, *strand*, *estuarine*, and *fluviatile* surfaces, with buried shells possibly the only marine deposits, except around open bays. Older formations may be largely subaerial deltas with eolian sand. Erratic

boulders and striated cobbles are fluviatile (Virginia; Wentworth, 1930) or on barrier islands (Maryland).

Progradation (shoreline outbuilding) on a stable or slowly emerging coastal plain completely covers marine bottoms of emerging equilibrium profile of continental shelf by subaerial deltas, shoreline (strand) deposits, and lagoon beds where wave-and-current energy (Price, in press) is high to medium by Gulf standards. Marine bottoms as now known may emerge noncatastrophically only around open bays and on rare, lee, nondeltaic coastal sectors, found chiefly on peninsula and island coasts, as northwest sectors of peninsulas of Florida and Yucatan.

GEOLOGIC EVIDENCE OF CHEMICAL COMPOSITION OF THE PRECAMBRIAN ATMOSPHERE

Kalervo Rankama
Institute of Geology, University of Helsinki, Helsinki, Finland

A Precambrian breccia from Suodenniemi, Finland, with an age approaching 2 billion years, consists of angular fragments of Precambrian diorite embedded in a fine-grained granoblastic cement of varying degree of schistosity and consisting mainly of quartz, biotite, hornblende, and oligoclase. This rock is interpreted as a genuine weathering breccia *in situ* (Sederholm), even though its cement may contain some material transported from the neighborhood (Eskola). Chemical analyses reveal the predominance of FeO over Fe_2O_3 in both unaltered diorite from a fragment in the breccia and the surrounding fine-grained schistose cement. Furthermore, there is no increase in the Fe_2O_3 content of the cement, as compared with the Fe_2O_3 content of the diorite fragment. These results are interpreted to indicate that weathering of the diorite and formation of the breccia took place in an atmosphere devoid of oxygen. They appear to lend support to Urey's hypothesis of a reducing early Precambrian atmosphere. Absence of atmospheric oxygen also explains the occurrence of reduced native carbon as a finely disseminated pigment in the surrounding Bothnian phyllites and, by analogy, the common occurrence of carbonaceous slates and graphitic schists in early Precambrian terranes.

PALEOZOIC SECTION IN THE EASTERN SIERRA NEVADA, MONO COUNTY, CALIFORNIA

C. Dean Rinehart and Donald C. Ross
U. S. Geological Survey, Menlo Park, Calif.

A roof pendant of approximately 25 square miles is exposed along the east front of the Sierra Nevada in southern Mono County, California.

The pendant contains more than 20,000 feet of weakly metamorphosed Paleozoic sedimentary rocks, ranging from Early Ordovician (Deepkill) to at least Pennsylvanian(?). The rocks of Ordovician age are the first to be reported from the Sierra Nevada and are the oldest Paleozoic rocks known in the range. In general, the sequence is homoclinal; the beds strike northwest, are overturned to the west, and dip steeply east. The eastern part of the pendant, however, is complicated by complex folds and faults. Bedding is preserved in much of the section, and crossbedding occurs locally; near the south end of the pendant metamorphism has obliterated much of the primary structure.

The section consists of three units 7000, 10,000, and about 3000 feet thick, respectively, from the base to the top. The lowest unit is argillite and interbedded marble and locally contains graptolites of Ordovician age (Deepkill and Normanskill). The graptolitic strata resemble parts of the Palmetto formation of the Silver Peak area in Esmeralda County, Nevada. The middle unit consists of siliceous hornfels, calcarenaceous orthoquartzite, and marble. A prominent blue-gray marble layer near the top of this unit contains productid brachiopods and abundant crinoid columnals of Pennsylvanian(?) age. The upper unit is siliceous hornfels and contains less well-preserved molds of brachiopods.

VARIATION DIAGRAMS ON TRIANGULAR CO-ORDINATES OF ORTHOMAGMATIC AND METASOMATIC SUITES

Forbes Robertson and G. E. Goodspeed
Department of Geology, University of Washington, Seattle, Wash.

Suites of chemical analyses of orthomagmatic rocks exhibit distinctive symmetrical patterns considered to represent different modes of magmatic differentiation. Metasomatic granitic rock suites, on the other hand, show erratic patterns. Mobilized feldspathized rocks show a tendency toward symmetrical patterns.

The diagrams are a modification of Larsen's triangular diagrams. Norms are computed from chemical analyses after the C.I.P.W. system and adjusted to 100 per cent. Feldspars, mafics, and quartz are plotted. (Silica deficiency is plotted below the zero quartz line.) The Or-Ab-An ratios are superimposed respectively. Lines connect the two points obtained from a single analysis and emphasize the symmetrical or erratic characteristics of the diagrams.

Orthomagmatic suites include: volcanic rocks from several localities; rocks from layered intrusions; and rocks from igneous granitic bodies of batholithic dimensions.

Metasomatic suites include rocks from localities where the interpretation of granitization has been advanced and also from localities where the field and petrographic evidence suggests granitization.

VERTICAL DIFFERENTIATION IN THE WHITE TANK QUARTZ MONZONITE

John J. W. Rogers
Geology Dept., Calif. Inst. Technology, Pasadena, Calif.

The White Tank quartz monzonite (Jurassic?) forms four distinct plutons in Joshua Tree National Monument just south of Twentynine Palms, Calif. The largest of these plutons (7 miles in diameter) shows a variation of composition and texture through a vertical range of 1000 feet from the actual roof to the lowest exposed rock (probably not the true base).

The principal upward changes in the pluton are: potash feldspar increases from 20 to 50 per cent; grain size of potash feldspar changes from 3 to 8 mm, and color changes from pink to gray; biotite decreases from 10 to 3 per cent; the principal plagioclase changes from $Ab_{70}An_{30}$ to $Ab_{85}An_{15}$; myrmekite and "vein" perthite increase. The ratio between the amounts of quartz and plagioclase is roughly the same throughout the pluton, and the sizes of quartz and plagioclase are constant. The upper part of the pluton contains irregular intergrowths between microcline and sodic oligoclase, distinct albitic borders on some plagioclase laths where they contact potash feldspar, and rare graphic texture. The myrmekite is largely restricted to the albitic rims.

The compositional and textural variations may be explained by simple crystallization differentiation of an intruded melt and enrichment of the later fluids in water. All the observed textural features may logically form by primary crystallization.

PETROGRAPHIC VARIATION IN THE ORISKANY SANDSTONE

Melvin A. Rosenfeld
Magnolia Petroleum Company, Dallas, Texas

Petrographic analyses were made on approximately 100 specimens from the 100,000 square-mile area of Oriskany sand occurrence in the Eastern United States. Multistage sampling ranging from outcrop selection to final selection of single grains for measurement comprised some probability stages and some nonprobability stages. Information necessary for adjusting the results is lacking, thus

the data describe a *sampled population* and, for the present, provide the only estimates available for the petrographic parameters of the initial Oriskany *target population*.

The *total* sandstone body is estimated to have a composition of 78% detrital silicates, 9% authigenic silica, 7% clastic carbonate, 4% crystalline carbonate, and 2% other minerals with virtually no detrital chert. The grain-size distribution is phi-leptokurtic and symmetrical with mean 1.69 ϕ (0.31 mm) and standard deviation 1.04. Azial-ratio distribution is platykurtic symmetrical with mean 0.677 and standard deviation 0.142. Distribution of two-dimensional azimuthal inclinations of long axes of grains is between parabolic and rectangular with standard deviation 47° and $\beta_2 = 2$. Packing index is 41%, and saturation porosity is 7.6%. The parameters of a *typical* (modal) specimen differ slightly from these *total* values.

Classification of the detrital silicates is based on objectively assessed quartz types, and a relationship between amount of bubble inclusions and type of extinction is developed. Other interrelationships among petrographic parameters are described, and geographic distributions of these properties are discussed. It is concluded that a large part of the Oriskany sand may be of first-cycle origin.

GOLDICHITE, A NEW HYDROUS POTASSIUM FERRIC SULFATE FROM THE SAN RAFAEL SWELL, UTAH

A. Rosenzweig and Eugene B. Gross
University of Minnesota, Minneapolis, Minn.; U. S. Atomic Energy Commission, Grand Junction, Colo.

Goldichite, a new hydrous potassium ferric sulfate from the Dexter No. 7 Mine, Calf Mesa, San Rafael Swell, Utah, has the composition $KFe(SO_4)_2 \cdot 4H_2O$. It occurs as radiating clusters of pale-green crystals or fine-grained crystalline encrustations. It is associated with coquimbite, halotrichite, roemerite, alunogen, copiapite, fibroferrite, melanterite, and other sulfates, which constitute the cementing material of a talus slope below a small, pyrite-rich uranium deposit in the Triassic Shinarump conglomerate. Crystals are commonly singly terminated, monoclinic-prismatic laths parallel {100} with forms {100}, {110}, and {011}. The space group is $P2_1/c$, and the cell constants are: $a_0 = 10.45$ Å, $b_0 = 10.55$ Å, $c_0 = 9.15$ Å, $\beta = 101°49'$. The cell contains four molecules; the density is 2.43 (observed) and 2.419 (calculated). The mineral is biaxial positive, with $2V = 82°$ (calculated), $\alpha = 1.582$, $\beta = 1.602$, $\gamma = 1.629$; X = b, Z $\wedge$ c = 11°.

The mineral is named in honor of Samuel S. Goldich, Professor of Geology at the University of Minnesota.

LAYERED BASIC INTRUSIVE, FAIRWEATHER RANGE, SOUTHEASTERN ALASKA

Darwin L. Rossman
U. S. Geological Survey, Menlo Park, Calif.

In 1952 the U. S. Geological Survey examined one of three known layered basic intrusive bodies in the Fairweather Range, southeastern Alaska. The body is roughly elliptical and is about 16 miles long and 8 miles wide. It is distinctly layered. The layers form a bowl-shaped structure similar to that of the Skaergaard complex, but this body differs in that the contacts are essentially vertical. About 32,000 feet of layered rock is exposed, but neither the top nor the bottom is visible. The structure, metamorphism of enclosing rocks, and contact relations suggest that the body is intrusive.

The rock-forming minerals, plagioclase and clino- and ortho-pyroxene, do not show significant change in composition throughout the entire sequence. The ratio of light to dark minerals within a layer or groups of layers suggests that the layers are genetically related and were formed by the same precisely repeated mechanism. A plot of the specific gravities of about 600 rock specimens shows no recognizable trend within the exposed portion. The relation of observed structures within layers to the genesis of the body is discussed.

SYNTHETIC ALKALINE EARTH GERMANATES ISOSTRUCTURAL WITH ENSTATITE AND PSEUDOWOLLASTONITE

Robert S. Roth
National Bureau of Standards, Washington, D. C.

Germanium dioxide, of the α-quartz structure, when heated with equi-molar per cents of MgO, CaO, SrO, and BaO, at 1235°C for 1 hour, was found to form ABO_3-type compounds. The $MgGeO_3$ compound was found, by x-ray diffraction, to be isostructural with enstatite ($MgSiO_3$). This Ge-enstatite is orthorhombic with a = 18.661 Å, b = 8.954 Å, and c = 5.346 Å. $SrGeO_3$ and $BaGeO_3$ have structures similar to pseudowollastonite (α-$CaSiO_3$). However, the structure of $CaGeO_3$ was not definitely established to be of this form. X-ray patterns of the pseudowollastonite-type structures indicate that larger A and/or B ions tend to increase the symmetry of the structure. Although α-$CaSiO_3$ itself is only pseudohexagonal, $BaGeO_3$ appears to be truly hexagonal.

As GeO_2 has a rutile type polymorph, with Ge^{+4} ions in octahedral co-ordination, it was thought possible that these silicate-type structures might have titanate-type polymorphs. GeO_2 can be readily formed in the rutile-type structure by heating the quartz-type polymorph at 700°C and 20,000 psi. However, the pseudowollastonite-type $BaGeO_3$, when heated under 20,000 psi at 700°C, showed no change in crystal structure. Differential thermal analysis of $BaGeO_3$ indicates a phase transformation at about 340°C. A 1% addition of Fe_2O_3 to $BaGeO_3$ causes an entirely different x-ray pattern which may represent the stabilized form of high-temperature $BaGeO_3$.

FAULT PATTERNS IN SOUTHEASTERN ALASKA

C. L. Sainsbury and W. S. Twenhofel
U. S. Geological Survey, Menlo Park, Calif.; Denver Federal Center, Denver, Colo.

Large linear features interpreted as faults were plotted from aerial photographs of southeastern Alaska, and the resultant patterns analyzed with reference to the literature and field relations determined by the writers and other geologists of the U. S. Geological Survey. The faults apparently belong to two well-defined systems which strike northwesterly and northerly, and two ill-defined systems which strike northeasterly and easterly. The fault zones are part of a system of fractures subparalleling the Coast Ranges, the Alaska Range, and the North Pacific coast of British Columbia and Alaska.

Movement on these fault zones in southeastern Alaska took place in pre-Upper Cretaceous time, during the Tertiary period, and possibly in Recent times. Displacement on one of the major fault zones is dominantly strike-slip, and strike-slip movement is indicated on a major lineament that can be traced for 1600 miles from southeastern Alaska northwest to and along the arcuate Alaska Range. Sufficient data are not available on displacements along other individual faults to permit an interpretation of the type and amount of movement.

The suggestion is offered that some of the mineral deposits of southeastern Alaska are genetically related to certain faults, particularly those of the northwest-trending system.

NORTH AMERICAN STEGOMASTODONTS

D. E. Savage
Department of Palentology, University of California, Berkeley, Calif.

Research on the sample of stegomastodonts, from the Cita Canyon locality in the Panhandle of Texas suggests that these animals are very useful in the correlation of widely scattered late Cenozoic sites in North America. When the evolutionary history of stegomastodonts is calibrated on the standard geochronological calendar, it may be seen that they originated suddenly, evolved rapidly, and existed for only a short time.

These elephantlike mammals and their flatter-skulled relatives, the cuvieronines, probably evolved from the rhynchotheres (break-jawed mastodonts) of the Hemphillian (middle Pliocene) of North America. Stegomastodonts are represented in the earliest Blancan (late Pliocene) faunas of Mexico and the southern United States and survived long enough to witness climatic changes associated with probably two continental glaciations. They were finally replaced by the mammoths, immigrants from Asia. Both stegomastodonts and cuvieronines dispersed to South America, probably in earliest Blancan time, and existed until after the time of man's arrival on that continent.

Small stegomastodonts from the early Blancan Rexroad, Benson, and Miñaca sites are very similar to South American representatives of the subgenus *Haplomastodon* and demonstrate morphological intermediacy between rhynchotheres and later stegomastodonts. Most of the large elephantine stegomastodonts of North America—particularly the local populations from the Blanco, Cita Canyon, and Deer Park localities (later Blancan of Texas and Kansas)—are referable to *Stegomastodon* (*Stegomastodon*) *mirificus* (Leidy), the genotypic species.

RECONNAISSANCE OF THE SYSTEM NA_2O-FEO-SIO_2

J. F. Schairer, H. S. Yoder, and A. G. Keene
Geophysical Laboratory, 2801 Upton St., N. W., Washington, D. C.

More than 70 separate compositions in the system Na_2O-FeO-SiO_2 have been prepared and studied by the method of quenching. The fields of fayalite, wüstite, tridymite, quartz, sodium metasilicate, and sodium disilicate have been delineated. There are many new ternary compounds whose compositions, fields of stability, and mutual melting relations are very difficult to determine because of the change in composition of melts by reaction with the container, an iron crucible, and because of the crowding of the fields of many of these compounds into a very small portion of the phase diagram. A preliminary diagram for this system is presented.

Phase data on this system and its analog Na_2O-MgO-SiO_2 are necessary before proceeding to studies of more complex systems which may help us to determine the relationships between alkaline pyroxenes and amphiboles which are important constituents of some of the alkaline rocks and minor mineral constituents of many igneous rocks.

VOLCANIC ROCKS OF SAIPAN, MARIANA ISLANDS*

Robert George Schmidt
U. S. Geological Survey, Washington, D. C.

The Mariana Islands are divisible into two chains—the southern Marianas, which include Saipan, aligned along an eastern arc and consisting of Tertiary volcanic rocks and limestones; and the northern Marianas, forming a western arc of Quaternary volcanoes.

The volcanic rocks of Saipan consist of dacitic and andesitic flows and pyroclastic rocks of Eocene and probable Oligocene age. Dacites are primarily silicic glass, oligoclase, silica minerals, and magnetite. Andesites are principally labradorite, hypersthene, augite, magnetite, silica minerals, and anorthoclase. The rocks are characterized by high silica and alumina and low potash. Quartz is universally present in the norm, attaining as much as 49 per cent in the dacites. The andesites are extremely calcic and contain a large excess of lime over alkalis.

The andesites and dacites of Saipan generally are close in composition to volcanic rocks of other islands in the system of arcs extending from Japan to Palau. Apparently the bulk of the volcanic rocks in this region form a well-defined petrographic province.

It is difficult to reconcile the andesitic and dacitic rocks with simple differentiation of a primary basaltic magma. Providing they are related to ancestral basaltic rocks, it seems necessary to assume assimilation of important amounts of siliceous and aluminous crustal material to account for their

* Publication authorized by the Director, U. S. Geological Survey

composition. The absence of basalts on Saipan and the wide compositional gap between the andesites and dacites may indicate that the andesitic and dacitic magmas originated independently.

MINERALOGICAL MAGIC NUMBERS

Cecil J. Schneer
University of New Hampshire, Dept. of Geology and Geography, Durham, N. H.

Axial ratios c/a in the proportions 2, 3, 4, 15, 6, 21, 8, . . ., recorded for one dimensional isomorphous series such as the rare-earth carbonates and iron-sulfate hydrates, and for one-dimensional polymorphs such as silicon carbide and zinc sulfide, can be explained by a superlattice principle of general applicability. Each axial ratio number represents the number of layers in the unit cell of a particular phase. The smaller layer numbers of the isomorphs occur at simple stoichiometric ratios of the end-member components. The smaller layer numbers of the polymorphs occur at simple stoichiometric ratios of the end-member structural arrangements. Choice of stoichiometric ratio is a function of temperature. Given a fixed stoichiometric ratio, summation of interaction potentials between layers shows that an orderly distribution of the two types of layers minimizes the potential. Superlattices result from ordering. The "magic numbers" remain, even with compositional departure from simple stoichiometric proportions, because of the higher entropy of the simple ratios. From this point of view, complete isomorphism or a continuous series is possible only with disequilibrium. At equilibrium, the stable phases form a discontinuous or discrete series.

PARAGENETIC RELATIONSHIPS OF GERMANITE AND RENIÉRITE FROM TSUMEB, SOUTH WEST AFRICA

C. B. Sclar and B. Geier
Battelle Memorial Institute, Columbus, Ohio; Tsumeb Corporation Ltd., Tsumeb, South West Africa

Germanium occurs as germanite and reniérite in the hypogene copper-lead-zinc ore body at Tsumeb, South West Africa. The principal hypogene sulfides that constitute the germanium-bearing ore are galena, tennantite, enargite, digenite, bornite, chalcopyrite, sphalerite, and pyrite. Germanite occurs as minute grains and fine-grained aggregates disseminated dominantly through massive granular aggregates of galena, tennantite, and sphalerite and subordinately through the host rock of dolomite. Reniérite occurs as (1) continuous and discontinuous shells of variable thickness around germanite grains and as intergranular networks in aggregates of germanite grains, (2) shells of variable thickness around inclusions of an unidentified mineral in germanite, (3) irregular patches within germanite grains, (4) lamellae of variable thickness developed along the cubic or octahedral planes of germanite so as to form a regular intergrowth with that mineral, and (5) irregular grains disseminated through the host rock of dolomite.

Germanite was one of the earliest minerals formed in the sequence of hypogene sulfide deposition, and reniérite was introduced later principally by replacement of the germanite and subordinately by replacement of the host rock. Replacement of germanite by an equal volume of reniérite requires an addition of iron and the corresponding removal of an approximately equivalent amount of germanium. The intimate association of early germanite and relatively late reniérite provides an example of the mineralogical redistribution of germanium induced by changing hypogene conditions.

CHEMICAL EVIDENCE OF POSSIBLE GRANITIZATION OF THE FORDHAM GNEISS, NEW YORK

David M. Scotford
Miami University, Oxford, Ohio

Evidence of a possible granitization origin for the Poundridge granite, Westchester County, New York, is afforded by calculations of Barth's standard rock cell. Since there is no evidence of any ex-

pansion in the migmatite, a comparison of the standard cells of the Fordham gneiss and the migmatite gives an accurate picture of the exchange of cations which produced the migmatite by metasomatism of the gneiss.

Cations added	*Cations subtracted*
4.3 Si	.1 Ti
2.8 K	1.5 Al
	1.2 Fe^{3+}
7.1 Cations representing	2.0 Fe^{2+}
20 valences	1.0 Mg
	2.1 Ca
	.6 Na
	.6 H
	9.1 Cations representing
	20 valences

A similar comparison of the migmatite and Poundridge granite indicates that the following exchange could have produced the granite.

Cations added	*Cations subtracted*
5.6 Si	.2 Ti
.1 Fe^{3+}	4.4 Al
1.1 K	.9 Fe^{2+}
	1.3 Mg
6.8 Cations representing	1.3 Ca
23.4 valences	1.3 Na
	1.2 H
	10.6 Cations representing
	23.5 valences

The very similar pattern of the two exchanges shows that the granite could well have been a product of the same metasomatic process which produced the migmatite. The difficulty in assuming the migmatite to be the result of the simple addition of silicon and potassium from a granite magma lies in accounting for the lost ions removed from the gneiss. There is nothing inconsistent in the composition of the Fordham gneiss to destroy the possibility that these ions were displaced outward into the surrounding gneiss. It is also possible that they became concentrated in the ubiquitous amphibolite layers which characterize the gneiss.

DELTA BUILDING IN THE NORTHERN GULF OF MEXICO*

F. P. Shepard and P. C. Scruton
Scripps Institution of Oceanography, La Jolla, Calif.

Deltas are building forward surprisingly fast into the open Gulf of Mexico and its embayments. Thus off three passes of the Mississippi a decrease in depth of more than 100 feet seems to have occurred during the interval between 1868 and 1940. These rapidly advancing slopes are cut by numerous gullies which differ from the heads of typical submarine canyons in having much lower gradients, hills and basin depressions along their courses, and in dying out along the slopes at depths commonly less than 200 feet.

* Work based largely on investigations carried out under A.P.I. Project 51

Most of the other principal streams along the northern Gulf are entering embayments which they are filling rapidly. During the past century growth up to 4 miles is found off the larger rivers, and the bay floors for some miles out beyond the river mouths have shoaled by several feet during the same period. In most places this shoaling decreases regularly out from the rivers. The Brazos of Texas has filled its old estuary and is now advancing rapidly into the open gulf along a diverted mouth.

The sediments deposited in front of the rivers in bays and open Gulf have some characteristics in common such as low sand content, appreciable percentage of plant fibers and ferruginous aggregates in the coarse fraction, and a low percentage of calcareous organisms, but an unusually high ratio of ostracods to Foraminifera.

APPROACH TO THE PALEOECOLOGY OF MAMMALS

J. Arnold Shotwell
Museum of Natural History, University of Oregon, Eugene, Ore.

The Tertiary adaptive radiation of mammals complicates the study of their paleoecology by the uniformitarian approaches used for other biota. Quarry faunas provide the most likely source of data in a quantitative approach. It is necessary to determine from quarry samples the number of communities represented, the community to which each species belongs, which community is proximal to the site of deposition (the major community), the relative abundance of species of the major community, and the special relationships of the major community habitat to the other habitats represented. The present approach derives this information from quarry samples by application of the following assumptions:

(1) Reasonably large collections from quarry accumulations are a random sample of what is present in the quarry, providing all specimens are retained from the volume of sediment worked.

(2) An indication of density of mammal species of the proximal community may be obtained from use of the *minimum number* (the least number of individuals which must be proposed to account for the specimens of each species present).

(3) Mammals whose community habitat in life was close to the site of deposition will be better represented than will those from habitats farther away.

The paleoecological implications of these assumptions have been tested by analysis of the Hemphill, Texas, and McKay Reservoir, Oregon, faunas, which show the contrasts expected both in the proximal community of each and in the density of species.

OBSERVATIONS BY DIVING GEOLOGISTS OF BEDROCK OFF SOUTHERN CALIFORNIA

George Shumway, R. S. Dietz, R. F. Dill, E. L. Hamilton, H. W. Menard, and D. G. Moore
Box 6571, San Diego, Calif.

The mode of occurrence of outcrops on the inner shelf and the erosive processes acting on them have been studied by the writers during more than 1500 dives made to depths between 15 and 150 feet. Bedrock outcrops are more prevalent than charts indicate. They occur chiefly in the "surge" zone—*i.e.*, the region between the breaker zone and about the 50- to 60-foot depth contour—where the effect of sea waves and swell produces oscillatory surges causing sediment transport and abrasive erosion.

The chief erosive processes affecting under-water outcrops are (1) the activities of rock-boring mollusks, echinoids, worms, and sponges; and (2) abrasion by water-carried rock particles. The oscillatory surging motion of water along the bottom becomes more turbulent in the vicinity of outcrops and tends to perpetuate them by inhibiting deposition around them. Differential erosion of more and less resistant layers of dipping sedimentary rock produces prominent strike ridges. Relatively soft rock of uniform resistance may form a flat and polished pavement covered by a thin layer of sand.

Rock-boring animals are almost universally present in large numbers in under-water outcrops. Their erosive effect is far more important than geologic literature indicates. They penetrate exposed surfaces to a depth of 3 or 4 inches, making it difficult for a diver to take a hand sample free from the effects of boring.

SYNTHESIS AND ATOMIC STRUCTURE OF LORENZENITE

Robert F. Shurtz
The Research Laboratory in Ceramics, The University of Texas, Austin, Texas

Lorenzenite is the naturally occurring compound $Na_2Ti_2Si_2O_9$ in which ZrO_2 may substitute for TiO_2 to the extent of nearly 12 per cent ZrO_2 by weight.

Synthesis of lorenzenite has been previously reported. This synthesis cannot be repeated, and it is shown here that rutile was mistaken for lorenzenite in this early report. A successful and reproducible synthesis from systems containing fluorine is described in this paper. The indices of refraction and the x-ray diffraction pattern of the synthetic lorenzenite confirm the synthesis.

The space group of lorenzenite has been reported as D_{2h}^{14}—Pbcn with a_0—14.51 Å., b_0—8.73 Å., and c_0—5.22 Å. This space group has been redetermined and confirmed using Weissenberg photographs. However, the orientation is found to be a_0—8.66 Å., b_0—5.18 Å., and c_0—14.42 Å. There are four molecules of composition $Na_2Ti_2Si_2O_9$ in the unit cell.

The atomic co-ordination scheme of lorenzenite has been deduced with sufficient accuracy that refinement by the use of Fourier or Patterson series would be relatively easy should such refinement become desirable. The structure consists of chains of titanium octahedra, similar to those in brookite, in parallel co-ordination with chains of silicon tetrahedra, similar to those in the pyroxenes. The growth habits, physical properties, and diffraction intensities are in accord with this preliminary structure for lorenzenite.

ISOTOPIC COMPOSITION OF CARBON IN PETROLEUMS AND OTHER ORGANIC CONSTITUENTS OF SEDIMENTS

S. R. Silverman and S. Epstein
California Research Corporation, P. O. Box 446, La Habra, Calif.; California Institute of Technology, Pasadena, Calif.

C^{13}/C^{12} ratios of petroleums and other organic sedimentary constituents vary by more than 3 per cent. C^{13} content of organic carbon occurring in nonmarine deposits is appreciably lower than that of organic carbon associated with marine sediments. This difference may be due to inherent differences in source materials because fresh-water plants and land plants contain less C^{13} than do marine plants and animals.

Variations in carbon-isotope abundances in petroleums are related also to petroleum composition. Paraffinic and naphthenic constituents separated in the laboratory from a California crude oil are low in C^{13} content, whereas aromatic constituents are enriched in C^{13} relative to the C^{13} content of the total crude oil.

PLEISTOCENE DRAINAGE HISTORY OF THE YANKTON AREA, SOUTH DAKOTA-NEBRASKA

Howard E. Simpson
U. S. Geological Survey, Denver Federal Center, Denver, Colo.

The area about Yankton, South Dakota, was partly covered by glaciers during the Nebraskan and Illinoian stages and the Iowan, Cary, and Mankato substages of the Wisconsin. Each glaciation caused the abandonment of parts of the existing drainage system and the cutting of new channels.

Generally these new channels were occupied temporarily, and on retreat of the glacier drainage returned to an earlier course. The most significant modification was the birth of the Missouri River during the Illinoian stage.

GAMMA-RAY LOGGING IN GROUND-WATER STUDIES

Herbert E. Skibitzke
Room 305 Federal Building, Phoenix, Ariz.

The use of gamma-ray logging in ground-water studies is discussed. The most widely used application has been for geologic correlation. The value of the method lies in the provision of means to obtain logs of wells in which the casing has been installed. Thus, a geologist can acquire information about an aquifer after it has been developed.

Problems have arisen, generally, because of the difficulty in separating small differences in activity levels owing to statistical variations in the recorded radiation log. The improvement of the recorded gamma-ray log for hydrologic studies has been limited by the cost of the equipment, as economy in engineering is usually of great importance in such studies. With economy in mind, consideration is being given to improvements in field equipment which will decrease the magnitude of statistical variations on the recorded log. These improvements all depend upon obtaining a better sampling of the gamma-radiation time rate.

FORM AND MODE OF EMPLACEMENT OF SILLS IN THE ELKHORN MOUNTAINS, MONTANA

Harry W. Smedes
U. S. Geological Survey, Spokane, Wash.

The abundant sills in the Late Cretaceous, pre-Boulder Batholith intrusive sequence in the Elkhorn Mountains in west-central Montana comprise basalt, lamprophyre, andesite, diorite, and granodiorite—with andesite and basalt prevailing—and are up to 2000 feet thick.

In strata of Belt and Paleozoic age, true sills predominate; injection dilation is the important mechanism of emplacement, and enclosing shales are contorted. In Cretaceous sedimentary rocks, intrusives tend to have concordant floors but partly discordant roofs with irregular upwellings and dike offshoots. Injection dilation was accompanied or followed by stoping and assimilation along the top.

In Upper Cretaceous volcanic rocks, sills are largely apophyses of larger plutons, are wedge-shaped, and are commonly divergent by forking or changing intrusion horizon. Depth of cover is slight.

In pre-volcanic rock, argillaceous horizons were preferred; in the volcanic rocks, true sills abound in bedded water-laid volcanic mudstones and siltstones and welded tuffs. In coarser, poorly bedded pyroclastics, diverging sills prevail; in volcanic breccias, sills have gradational, ill-defined contacts masked by country-rock recrystallization and local assimilation.

In a unique sill type in water-laid bedded volcanic sedimentary rocks country rock is intimately mixed with thick marginal zones of amygdaloidal igneous rock; each retains its own characteristics even on a microscopic scale. Observations of dike offshoots from the basal amygdaloidal zone cutting through the sill support the hypothesis that these zones acquired water from moist semiconsolidated sediments. Assimilation was very slight, and the roof was gently deformed.

EOLIAN SAND ON DESERT MOUNTAINS*

H. T. U. Smith
University of Kansas, Lawrence, Kansas

Encroachment of eolian sand on the slopes of desert mountains has been observed in the Saharan Atlas, the Humboldt Basin area, the desert region of southern California, and the coastal desert of

* Based on research carried out under the auspices of the Office of Naval Research, contract Nonr-583(06).

Peru. The phenomenon is exceptionally widespread and prominent in the latter region. Sand deposits occur on both windward and leeward sides of the mountains, and are at horizontal distances of as much as several miles, and vertical distances of up to more than 1300 feet, from source areas in coastal flats or desert basins. On the windward side, the deposits generally are of irregular form, and the mountains may be described as sand-based, sand-drifted, sand-flanked, or sand-embayed, according to the form and extent of the accumulation. On the leeward side, the deposits range from irregular drifts through sand "cascades" or "glaciers" to sharp-crested longitudinal ridges of great size, which commonly give way to trains of barchans in a downwind direction. In some places the mountains or peaks are entirely surrounded by eolian sand. In a few places, hills or mountains are completely buried under sand accumulations, one in southern Peru to a depth of many hundred feet.

Under suitable conditions, sand deposits of the above types provide evidence of recent climatic fluctuations expressed by changes in the intensity of wind action. At many places in the Mojave desert region, discontinuities between leeward sand deposits and source areas, together with partial stabilization of the sand surface by a litter of rock chips, indicate that present eolian activity is less vigorous than that at some time in the geologically recent past.

MAPPING BEDROCK WITH LOW-FREQUENCY SOUND

W. O. Smith, G. B. Cummings, and J. E. Upson
Water Resources Division, U. S. Geological Survey, Washington, D. C.

During the past several years the Geological Survey, with collaboration of the Navy, has been investigating the use of low-frequency sound in the mapping of bedrock overlain by shallow sediments. The studies have been confined to saturated sediments covered by water with depth varying from a few feet to several hundred feet.

There have been three investigations: the Lake Mead Survey, the Chicago Bedrock Survey, and the Passamaquoddy Bay Studies. A preliminary study is being made in the Long Island Sound area. In each of these studies equipment and techniques have been progressively improved.

In these investigations the nature of the sediment plays a dominant and often complicated part in their acoustic response. The sediment may consist of gravel, sand, silt, or clay in various proportions. Often organic matter is present. The clays are in general plastic and present many complications. The physical conditions, especially as they relate to water, are important. The sound frequencies in use at present are of the order of 6 KC. Transducers have now been built to provide considerably increased output of acoustic power.

INFLUENCE OF GEOLOGIC CONDITIONS ON DESIGN OF BRIDGE FOUNDATIONS FOR THE LOS ANGELES FREEWAY SYSTEM

Ted L. Sommers
Bridge Dept., California State Division of Highways, Los Angeles, Calif.

More than 425 foundation studies have been completed from 1948 to 1954 for Los Angeles freeway structures. Engineering geology and soil mechanics together with modern tools and techniques are utilized to the fullest extent during the structure foundation studies. Interpretation of geologic conditions by engineering geologists at each structure site along the freeway routes has resulted in safe, economical design and construction.

In subsurface exploration the most common rock types are Recent and Pleistocene alluvium, Upper Miocene shale and sandstone, and a basement complex of undifferentiated granitic and metamorphic rocks.

Structures can be safely supported by spread footings or end-bearing piles resting upon Pleistocene alluvium or older rocks

Foundations supported by friction piles in Recent alluvium present a problem owing to the ex-

cessive compressibility of the material under even moderate loads. Settlements up to 2.4 feet have been recorded on load-settlement graphs. While striving to anticipate and correct such difficulties, the engineering geologist must be constantly alert to avoid the great expense of excessively long piles to support the structure. It is often more advantageous to surcharge the site with a high fill and secure consolidation of the sediments in advance of construction. Then, after removal of the surcharge, the structural load can be supported by relatively short friction piles.

ORIGINAL RADIOGENIC LEAD, AN ADDITIONAL CORRECTION FOR LEAD-URANIUM AND LEAD-LEAD AGE CALCULATIONS

L. R. Stieff and T. W. Stern
U. S. Geological Survey, Washington, D. C.

The age of uranium ore minerals can be determined from the Pb^{206}/U^{238}, Pb^{207}/U^{235}, and Pb^{207}/Pb^{206} ratios. In general the following sequence of ages results: Pb^{206}/U^{238} youngest, Pb^{207}/U^{235} slightly older, and Pb^{207}/Pb^{206} much older than both lead-uranium ages. Wickman has attributed this sequence of ages to the much greater loss of radon compared to actinon, gaseous daughter products in the U^{238} and U^{235} series, respectively. Some investigators prefer the Pb^{207}/U^{235} age because it is essentially unaffected by loss of actinon.

Possible alteration and the loss of uranium or lead, or both, have led some recent investigators to choose the Pb^{207}/Pb^{206} age. This age calculation should be satisfactory if corrections for radon loss, original lead, and mass spectrometric errors are small.

Kovarik and others have mentioned that the absence of original radiogenic lead is a necessary condition for satisfactory age determinations. Recent studies on lead minerals and uranium ores from the Colorado Plateau province have shown that these uranium ores contain at least two generations of radiogenic lead: original radiogenic lead deposited with the uranium, and radiogenic lead formed after deposition by the decay of the uranium. The correction of Plateau uranium ores with the average isotopic composition of Plateau lead minerals still results in a large discrepancy between Pb^{206}/U^{238} and Pb^{207}/Pb^{206} ages. Added corrections for the isotopic composition of the original radiogenic lead, which has also been found in certain Colorado Plateau province lead minerals, bring the Pb^{206}/U^{238}, Pb^{207}/U^{235}, and Pb^{207}/Pb^{206} ages into agreement within limits of experimental error.

LATE TERTIARY MARSUPIALS FROM SOUTH AUSTRALIA

R. A. Stirton
Department of Paleontology, University of California, Berkeley, Calif.

Late Tertiary vertebrate remains have been found on the west side of Lake Palankarinna, east of Lake Eyre, South Australia. The assemblage has been named Palankarinna fauna (Stirton, Rec. S. Aust. Mus., 1954). The stratigraphic unit in which it occurs has been described as the Etadunna formation by G. D. Woodard. The mammalian fossils were abundant in a channel deposit called the Woodard locality. The age is probably early or middle Pliocene.

Preliminary studies indicate that the following mammals are present:

A new genus and new species of peramelid more closely related to the bilbies than to *Peramdes* and *Thylacis* (=Isoödon) but in some features displaying relationships with these genera.

A phascolarctid specimen not adequate for a diagnosis (it was found at a lower level than the Woodard locality) is clearly nearer to the koala than to *Pseudocheirus*, *Schoinobates*, *Hemibelideus*, or *Petropseudes*. It also differs from *"Pseudochirus(?)" notabilis* DeVis 1889 in certain details.

A new genus and new species of macropodid has some characters in common with the wallabies and others that resemble *Protemnodon*. It may represent a proximity to a common ancestor of both genera.

A new genus and new species of a notothere, and remains of another notothere not adequate for a diagnosis share characters with most of the proposed genera and species of the Nototherinae.

CYCLICAL DEPOSITION OF FLUVIAL SEDIMENTS

Wm. Lee Stokes
Dept. of Geology, University of Utah, Salt Lake City, Utah

During an intensive study of the stratigraphy of the uranium-bearing Salt Wash sandstone member of the Morrison formation in the Colorado Plateau, certain repetitions of sedimentary types were noted. A typical association consists of: (1) a massive-appearing, thick-bedded, friable, generally light-colored sandstone, the constituents of which are of fine to medium size and fairly well sorted. This is overlain by (2) a more resistant, cross-bedded, darker sandstone with coarser, less well-sorted grains. Between the two types is an erosional unconformity along which are scattered pebbles of clay and shale. The typical outcrop is an overhanging cliff of the resistant phase upon a retreating wall of the softer phase.

A similar arrangement of beds has been noted in at least seven other formations including the Mesa Verde, Burro Canyon, and Wasatch. Examination of published photographs of many western formations shows the feature to be common.

Exact meaning of the sedimentary association is not clear; it may be tentatively assumed that the massive phase is deposited during low water and the cross-bedded phase during flood stage, but the time involved is uncertain.

PTERODACTYL TRACKS FROM THE MORRISON FORMATION NEAR CARRIZO MOUNTAINS, ARIZONA

Wm. Lee Stokes
Dept. Of Geology, University of Utah, Salt Lake City, Utah

During the summer of 1952 a series of tracks of a pterodactyl was found in the Morrison formation near the Carrizo Mountains, Arizona. Six feet of trackway was collected, containing eight impressions of each manus and pes. Length of pace is about 14 inches, and width of trackway 6 inches, but the spacing of the tracks is uneven. The pes mark shows four toes and a narrow pointed heel; the manus impression which is immediately behind the pes is deeply indented and shows the presence of two short, claw-bearing digits and a longer trailing one which supported the wing membrane. The tracks are excellently preserved and can be attributed to no other group of animals except the pterodactyls.

This is the first recorded discovery of pterodactyl tracks. It is also the second fossil indication of the group from the Jurassic of the Western Hemisphere. The tracks give good evidence that the animal could and did walk and that the pose was quadrupedal. The geologic setting also shows that the animal lived hundreds of miles from the nearest ocean, perhaps even in a semiarid environment

QUATERNARY HISTORY OF THE SOUTHEASTERN SAN JOAQUIN VALLEY, CALIFORNIA, INTERPRETED FROM LITHOFACIES MAPS

Robert Stone
Geology Department, University of California at Los Angeles, Los Angeles, Calif.

Lithofacies maps showing contours based on relative proportions of gravel, sand, and clay in more than 300 water wells can be used to reconstruct the Quaternary history of the southeastern San Joaquin Valley. Cored wells serve as a control for the interpretations.

Maps drawn for three successive intervals show:

The last great uplift of the Sierra Nevada stimulated the construction of alluvial fans which have been growing ever since. Growth of these fans has caused migration, generally away from the mountains, of areas receiving finer sediments. At least one of these interfan areas was occupied by an intermittent lake that was connected at times with other Pleistocene lakes of the San Joaquin Valley.

The origin of this lake was probably due as much to tectonic activity as to the growth of the fans. The White Wolf fault apparently formed the southern boundary of the lake and separates fine-grained lake sediments from coarse fanglomerates.

A buried alluvial fan opposite a large wind gap in Wheeler Ridge confirms the interpretation of the origin of this wind gap reached on physiographic evidence alone—that is, defeat of an antecedent stream flowing across the rising structure.

RELIABILITY OF SIMPLIFIED SLOPE-SAMPLING METHODS

Arthur N. Strahler
Department of Geology, Columbia University, New York, N. Y.

Statistics describing steepness of ground surface slope have geomorphic, hydrologic, engineering, and military applications. Two rapid methods of sampling slope were tested for reliability: (1) location of sampling points by drawing random pairs of rectangular co-ordinates, and (2) use of sampling points uniformly spaced on a rectangular grid. A test area of about 1 square mile was selected near the center of the Emporium, Pennsylvania, topographic quadrangle (U. S. Geological Survey, 1:24,000) and includes the greater part of two typical second-order drainage basins.

In an attempt to measure the complete slope population, or universe, within the test square a slope map was contoured from slope-tangent values determined at about 1500 points on the topographic map. By planimeter measurement of areas between successive slope contours a percentage frequency-distribution histogram was obtained, representing the entire slope population. Samples of 100 points each were then taken directly from the topographic map by both random co-ordinate and grid methods and compared with the slope population. In tests using the statistic χ^2/d.f. the hypothesis that sample and population variances are equal was accepted at the 5 per cent level of significance for both methods of sampling. In tests using the statistic z the hypothesis that sample and population means are equal was also accepted at the 5 per cent level for both methods. Thus under conditions prevailing in this investigation the mean and variance may be satisfactorily estimated by either of the shorter methods.

STRATIGRAPHIC RELATIONS IN THE CARRIZO MOUNTAINS AREA, NORTHEASTERN ARIZONA AND NORTHWESTERN NEW MEXICO

J. D. Strobell, Jr.
U. S. Geological Survey, Grand Junction, Colo.

Formations exposed in the Carrizo Mountains area range in age from Permian to Eocene (?). The De Chelly sandstone member of the Cutler formation (Permian) is underlain by Cutler red beds and unconformably overlain by Shinarump conglomerate (Late Triassic); the Moenkopi formation (Early and Middle? Triassic) is absent. The Chinle formation (Late Triassic) is restricted to Gregory's lower three divisions; red siltstone of Gregory's "A division" is now the lower member of a twofold Wingate sandstone that is assigned to the Triassic system on evidence gained by J. W. Harshbarger and associates elsewhere in the Navajo country. The Kayenta formation (Jurassic?) and Navajo sandstone (Jurassic) thin southeastward and disappear within the Carrizo Mountains area. The San Rafael group (Middle and Late Jurassic) comprises five formations: Carmel formation, Entrada sandstone, Todilto limestone, Summerville formation, and Bluff sandstone. Carmel is present only in the western half of the area, and Todilto only along the eastern edge. Where Carmel pinches out, Entrada rests unconformably without detected angularity upon Wingate.

The Morrison formation (Late Jurassic) comprises four members—Salt Wash, Recapture, West-

water Canyon, and Brushy Basin. Possible equivalents of the Burro Canyon formation (Early Cretaceous) are not differentiated from the Morrison. Dakota sandstone (Late Cretaceous) unconformably overlies the Morrison and is conformably succeeded by marine Mancos shale. Nondeposition of Moenkopi, convergence of Kayenta, Navajo, Carmel, and Todilto, and thinning and lithologic change in other formations suggest intermittent uplift during Mesozoic time. These rocks were folded, truncated, and subsequently covered by Chuska sandstone (Eocene?).

THREE NEW CYSTIDS FROM THE DEVONIAN TRAVERSE GROUP OF MICHIGAN

Erwin C. Stumm
Museum of Paleontology, University of Michigan, Ann Arbor, Mich.

The upper Middle Devonian cystid genus *Lipsanocystis* from the Traverse group of Michigan is one of the youngest known. It has previously been known from the type species *L. traversensis* which occurs in the Thunder Bay limestone. Three new species are described from other formations in the Traverse group. Comparison of these with the type species shows that the pinnule sockets in the ambulacra range from four to eight pairs in the different species. Anal plates are preserved on two of the three new species and have been found on a recently collected specimen of the type species. They consist of 12 rectangular peripheral plates and 6 or 7 triangular axial plates. Ornamentation on the thecal plates consists of tubercles, ridges, or both, and they may be arranged radially, concentrically, or irregularly. The species of *Lipsanocystis* are distinguished from the species of *Strobilocystites* from the Cedar Valley limestone of Iowa in having unbranched ambulacra. The types of the species of *Strobilocystites* are refigured for comparison.

RADIOCARBON MEASUREMENTS AT THE U. S. GEOLOGICAL SURVEY

Hans E. Suess and Meyer Rubin
U. S. Geological Survey, Washington, D. C.

During the past year a method for C^{14} determination has been developed and applied at the U. S Geological Survey in Washington. Employing acetylene as a counting gas, the method extends the age limit for radiocarbon dates to almost 40,000 years. So far, about 100 dates have been obtained by this method. Our main object has been the dating of pre-Mankato material and the establishing of an absolute time scale for glacial events in the later part of the Wisconsin age. The results show for example that a major glacial advance took place in North America about 20,000 years ago, penetrating in certain areas farther south than any previous glacier in the Wisconsin age.

Further investigations were made on general questions such as the suitability of carbonate samples for dating.

TITANCLINOHUMITE IN KIMBERLITIC TUFF, BUELL PARK, ARIZONA*

Ming-Shan Sun
New Mexico Bureau of Mines and Mineral Resources, Socorro, N. M.

Titanclinohumite, one of the prominent constituents of a kimberlitic tuff plug in Buell Park about 15 miles north of Ft. Defiance in northeastern Arizona, is anhedral without twinning or cleavage. Some large grains resemble black obsidian. Fragmental grains range from 15.5 mm to about 1 mm in diameter. Large grains of titanclinohumite as well as grains of olivine, enstatite, pyrope garnet,

* Publication authorized by the Director, N. M. Bureau of Mines and Mineral Resources

ilmenite, and other minerals are brought to the surface in ant hills in alluvium, largely derived from kimberlitic tuff.

Physical and optical properties: subtranslucent, luster subvitreous and slightly resinous, fracture uneven to subconchoidal, brittle, H. = 6.5 to 7, G. (measured) = 3.364. Color black to blackish brown. Streak yellowish brown. Optically positive. $2V_D = 56°$. Indices of refraction for D light at 25°C: nX = 1.707, nY = 1.714, nZ = 1.734. Both inclined and horizontal dispersion are strong.

X-ray studies both by Laue and rotation methods showed this titanclinohumite to be monoclinic, with $\beta = 101° 7'$. Cell dimensions: $a_0 = 13.643$ Å, $b_0 = 4.809$ Å, $c_0 = 10.232$ Å.

Spectrographic analyses indicate that the same trace elements are present in the titanclinohumite, olivine, and garnet of the kimberlitic tuff. However, there is no evidence that this titanclinohumite was derived from olivine by deuteric alteration. Partial data of chemical analysis are: TiO_2 5.11%, Fe_2O_3 1.23%, FeO 10.20%, F 0.06%, H_2O^+ 1.14%.

GEOCHEMICAL ASPECT OF THE VOLCANIC ROCKS OF CIENEGA, NEW MEXICO*

Ming-Shan Sun and Brewster Baldwin
New Mexico Bureau of Mines and Mineral Resources, Socorro, N. M.

Six main volcanic units occur at Cienega, 15 miles southwest of Santa Fe, New Mexico. Andesite breccia, resting on late Eocene Galisteo formation, was domed by monzonite, which in turn was eroded and buried by calcic and glassy latite breccia and Cieneguilla limburgite. Pleistocene gravel and basalt bevel this sequence.

Refractive indices of 80 fused samples, ranging from 1.525 to 1.646, reflect the silica content, ranging from 69.04 to 38.99 per cent. Spectrographic analyses show that nickel, vanadium, and chromium vary inversely with silica content.

The rock standard cells, derived from complete chemical analyses by methods of Barth and Eskola, are presented in the following modified Holmquist chemical formulae.

Glassy latite: $Si_{61.59}Al_{18.20}Fe^{3+}_{2.45}Fe^{2+}_{0.40}Mg_{0.66}Ca_{3.24}Na_{8.53}K_{4.37}Ti_{0.38}P_{0.12}Mn_{0.06}[O_{162.26}(OH)_{7.56}]_{169.82}$

Monzonite: $Si_{57.22}Al_{18.14}Fe^{3+}_{3.73}Fe^{2+}_{0.68}Mg_{1.76}Ca_{5.79}Na_{7.16}K_{4.69}Ti_{0.47}P_{0.23}Mn_{0.13}[O_{159.45}(OH)_{7.22}]_{166.67}$

Calcic latite: $Si_{52.26}Al_{19.20}Fe^{3+}_{5.32}Fe^{2+}_{0.97}Mg_{2.53}Ca_{6.60}Na_{7.48}K_{4.57}Ti_{0.60}P_{0.41}Mn_{0.06}[O_{154.28}(OH)_{10.68}]_{163.06}$

Basalt: $Si_{47.92}Al_{16.37}Fe^{3+}_{3.12}Fe^{2+}_{8.57}Mg_{9.07}Ca_{9.40}Na_{6.01}K_{2.49}Ti_{1.08}P_{0.85}Mn_{0.12}[O_{148.83}(OH)_{13.92}]_{162.75}$

"Limburgite": $Si_{43.84}Al_{15.98}Fe^{3+}_{3.75}Fe^{2+}_{5.93}Mg_{12.54}Ca_{9.69}Na_{4.62}K_{1.05}Ti_{1.17}P_{0.22}Mn_{0.15}C_{1.15}$
$[O_{145.75}(OH)_{15.63}]_{161.38}$

Limburgite: $Si_{36.97}Al_{12.69}Fe^{3+}_{2.95}Fe^{2+}_{5.14}Mg_{19.61}Ca_{13.09}Na_{6.21}K_{0.86}Ti_{1.84}P_{0.53}Mn_{0.06}Cr_{0.05}$
$[O_{128.83}(OH)_{10.18}S_{0.04}]_{149.05}$

The total number of anions, including hydroxyl and nonoxygenous anions such as sulfur, is directly proportional to cation number of Si. The number of Ti increases with decrease of Si.

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* Publication authorized by the Director, New Mexico Bureau of Mines and Mineral Resources

CORRELATION OF THE CARBONIFEROUS AND PERMIAN FORMATIONS IN THE CANADIAN ROCKY MOUNTAINS

Patrick K. Sutherland
Department of Geology, University of Houston, Houston, Texas

Field investigations in northeast British Columbia make possible preliminary correlations in the Upper Paleozoic strata from Alberta northwestward to the Yukon.

The limestones and shales of the Mississippian Banff and Rundle formations change in character northward and have not been recognized north of Wapiti Lake. A new unit, comprising cherts and limestones of early and Middle Mississippian age, is found in the Halfway-Prophet rivers region. Northwest of the Prophet, on the Alaska Highway, the lower Kindle formation changes to include Middle and possibly Upper Mississippian shales, limestones, and sandstones; fauna also changes. In the Liard Range, the Lower Mississippian also is represented. Throughout the region the main Mississippian faunas consist of brachiopods and corals. Descriptions of the unusual tetracorals are in press.

The lithologically variable Pennsylvanian-Permian? Rocky Mountain formation of Alberta includes quartzitic sandstones, cherts, and dolomites. Over 600 feet in thickness at Banff, it thins to 75 feet at Kakwa Lake and is missing at Wapiti where Triassic rests on Mississippian. Pennsylvanian and Permian? limestones and shales occur near Pine and Peace rivers but are absent in Halfway and Prophet regions where again Triassic overlies Mississippian. On the Alaska Highway, the Kindle formation contains Pennsylvanian brachiopods in its upper limestones and is overlain by Pennsylvanian or Permian bedded chert. In the Liard Range thick Pennsylvanian sandstones and shales are overlain by Pennsylvanian or Permian chert. Thus the irregularities in the character of the Pennsylvanian-Permian? strata and the changing magnitude of the sub-Triassic unconformity are demonstrated.

GEOLOGY AND MINERALOGY OF SALT AND CAP ROCK OF U. S. GULF COAST SALT DOMES

Ralph E. Taylor
Humble Oil & Refining Company, Houston, Texas

Active development of oil, salt, and sulfur resources during the last 15 years has greatly increased knowledge about salt domes. The 235 domes proved by drilling and many additional "geophysical prospects" occur in closely related Gulf Coast basins extending from Alabama to Mexico.

Typically, the salt of domes is a compact aggregate of halite grains associated with varying amounts of disseminated sand-size anhydrite grains concentrated in complexly folded bands. Sedimentary origin of the salt is known from its chemical and mineral composition, banding or bedding, and inclusions of gas, liquid, and fragments of anhydrite, sand, and shale beds. Anhydrite and some 20 other minerals associated with halite were formed by precipitation from sea water during halite deposition. Deep wells at margins of basins have cored horizontally bedded salt that has been called Jurassic; dome salt is different mineralogically and is probably older.

Additional evidence that cap rock is residue accumulated after solution of dome salt has been provided by discovery that at most domes the salt contains large quantities of anhydrite grains.

Distinctive inclusions of bedded anhydrite found recently in both salt and cap rock cores from the same domes also indicate residual origin.

The new data substantiate the theories of intrusive origin of salt domes from deposits of bedded salt and residual origin of cap rock from solution of this salt. Salt is mined at a number of domes, and cap rock is important in production of oil and sulfur at several.

ASSOCIATION OF MAN AND EXTINCT MARSUPIALS IN NEW SOUTH WALES, AUSTRALIA

Richard H. Tedford
University of California Museum of Paleontology, Berkeley, Calif.

The association of fossil mammal and human remains at Lake Menindee, New South Wales, discovered in 1939 by the joint Harvard-Adelaide Universities Expedition was reinvestigated in 1953 by a party from the University of California Museum of Paleontology and the South Australian Museum.

Preliminary results of the latter investigation confirm the association of stone and bone artifacts and fragmentary human remains with the remains of such extinct marsupials as *Diprotodon*, *Procoptodon*, *Protemnodon*, *Sthenurus*, and *Propleopus*. A number of extant forms were also associated. Bones of *Thylacinus* and *Sarcophilus* were fairly abundant. No materials attributable to the Dingo (*Canis*) were found.

The fossil remains and artifacts were contained in the lowest unit of a series of superimposed aeolian deposits now exposed in blow-outs along the northern shore of Lake Menindee near the Darling River in western New South Wales. The accumulation of animal remains is thought to represent a kitchen midden as many of the bones show evidences of charring, and flakes of charcoal were scattered in the deposit. Overlying units produced only a few animal bones and several human burials.

ISOTOPIC COMPOSITION OF LEAD IN OLIVINE BOMBS

G. R. Tilton, C. C. Patterson, and G. L. Davis
Dept. of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, D. C.; Dept. of Geol. Sciences, Calif. Inst. of Technology, Pasadena, Calif.; Geophysical Laboratory, Carnegie Institution of Washington, Washington, D. C.

Two laboratories have conducted independent studies of the isotopic composition of lead in three olivine bombs of Quaternary age. Diopside separated from a bomb from Dreiser Weiher, Germany, contained 2 parts per million lead with an isotopic composition of 206/204 = 19.5, 207/204 = 15.5, 208/204 = 39.7. The uranium content of the diopside was determined by isotope dilution to be 0.0067 parts per million. Lead in the diopside of a second bomb from San Bernardino, California, had a concentration of 2 parts per million and an isotopic composition almost identical with that of the Dreiser Weiher bomb. An olivine bomb from the western branch of the 1800 flow, Hualalai Volcano, Hawaii, contained 1 part per million lead in the composite bomb with an isotopic composition of 206/204 = 19.29, 207/204 = 15.45, 208/204 = 37.95.

These data indicate that the lead in the bombs has spent most of its past history in an environment with a much higher ratio of uranium to lead than that found in the bombs today. The uranium now in the diopside of the Dreiser Weiher bomb would have changed the 206/204 ratio of its lead by only 0.7 per cent in the past 4.5 billion years. Because of this evidence of extreme differentiation, we believe that the bombs may not be representative of the chemical composition of their source materials.

The leads in all three bombs show abnormally high 206/204 ratios relative to their respective

207/204 ratios when compared to the average young ore lead. This could be explained as contamination by young, or lately formed radiogenic lead, although it is difficult to envisage a mechanism for such a process.

LATE NORIAN (TRIASSIC) FAUNA IN SOUTHERN YUKON AND WESTERN BRITISH COLUMBIA, CANADA*

E. T. Tozer
Geological Survey of Canada, Ottawa, Canada

Stratigraphic revision of the Lewes River group of southern Yukon has shown that beds with corals, echinoids, *Spondylospira* and other brachiopods, *Paracochloceras*, and many pelecypods overlie beds with the late Norian *Monotis subcircularis* Gabb. Restudy of the Sutton limestone of Vancouver Island has yielded the late Norian *Cycloceltites* cf. *arduini* (Mojsisovics) and many pelecypods. Study of collections made by J. A. Jeletzky from beds above those with *Monotis* on the west coast of Vancouver Island has revealed the presence of *Spondylospira*, *Paracochloceras*, and several pelecypods identical with those of the Lewes River and Sutton formations. These three faunas have much in common with one another and with that of the Tyaughton group, described by F. H. McLearn, which occurs in beds of as yet undetermined stratigraphic relationships in southwestern British Columbia. All four are correlated with one another and are dated as late Norian; they represent a predominantly benthonic faunal facies hitherto unrecognized in the late Norian of North America; the commoner facies of this part of the stage comprises well-bedded black shales and argillaceous limestones with the probably epiplanktonic *Monotis*. In view of this facies difference the occurrence of the benthonic fauna above the *Monotis* beds does not establish that *Monotis subcircularis* did not range to the top of the Norian, particularly as closely related or identical forms are said to range to the top of that stage in Austria.

Spondylospira and many pelecypods in this fauna are very similar to species in the Norian of Peru.

GEOTHERMAL GRADIENTS AND GRANITE MAGMAS

O. F. Tuttle
Division of Earth Sciences, The Pennsylvania State University, State College, Pa.

Melting relations in the system albite-orthoclase-quartz-water can be used to speculate on the existence of granite liquids in the earth's crust if certain assumptions are made as to the geothermal gradients in the outer portion of the crust. In general, the measured geothermal gradients fall in the range 5°C/km to 60°C/km. In the zone of observation the gradients increase with depth at an average rate of 6°C/km/km because of the decrease in conductivity of rocks with increasing temperature.

In a region in which the initial observed gradient is 50°C/km melting of rocks of granite composition is expected between 9 and 12 kilometers depth, and with an initial gradient of 30°C/km melting is expected between 12 and 20 kilometers depth. If sufficient water and other volatile materials are present *complete melting* will take place under these conditions. Partial melting will occur if volatile materials are present in excess of that required to satisfy the equilibrium requirements of the hydrous crystalline phases. It is therefore probable that granite liquids are present at all times in the earth's crust in regions where granitic compositions and the requisite volatile content persist to depths of 20 kilometers and where the initial thermal gradient is steeper than about 25°C/km. If the rocks are extremely low in volatiles (*i.e.*, less than 0.5%) melting will not take place above a depth of 20–40 kilometers.

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SYNTHESIS OF THE HUMITES

A. Van Valkenburg, Jr.
National Bureau of Standards, Washington, D. C.

The humites are neosilicates of magnesium containing fluorine and hydroxyl. Their general formula is expressed as $nMg_2SiO_4 \cdot Mg(F, OH)_2$ in which n = 1 norbergite, 2 chondrodite, 3 humite, and 4 clinohumite. Fluorine end members have been synthesized from melts and solid-state reactions. No success was obtained in synthesizing compositions where n was greater than 4 or less than 1. The humite synthesis using hydrothermal techniques has been accomplished, and partial substitution of OH for F has been achieved. No completely hydroxyl end member of the series has been synthesized, and it is concluded that none exists. Data based on phase determinations using quench techniques indicate the fluorine end members are an incongruent melting series. The optical constants of the fluorine end members are:

	α	β	γ	2V
Norbergite	1.548	1.552	1.570	33°
Chondrodite	1.582	1.594	1.612	50°
Humite	1.598	1.606	1.630	59°
Clinohumite	1.608	1.618	1.636	76°

The x-ray powder data of the synthetic humites agrees well with the recent published work on natural humites by T. G. Sahama.

WALLROCK ALTERATION IN THE BROKEN HILLS RANGE, NEVADA

Charles J. Vitaliano
Department of Geology, Indiana University, Bloomington, Ind.

Investigation of a "talc" deposit which gave high Al_2O_3 analyses showed considerable quantities of associated sericite and chlorite. The deposit occurs north of Gabbs, Nevada, in the Broken Hills Range and is the result of wallrock alteration of a rhyolite porphyry along a vertical fissure.

Chemical analyses show an increase of MgO and a correlative decrease of SiO_2, Al_2O_3, K_2O, and Na_2O across the alteration zone toward the fissure. Thin-section study shows an orderly selective replacement of biotite, feldspars, and quartz in the host rhyolite. Introduced minerals are sericite, green chlorite flakes, sericite (second stage), talc, tourmaline, and chlorite in fine-grained aggregates.

Alteration was the result of MgO-bearing hydrothermal solutions moving upward along the fissure and outward into the wallrock. Except for tourmaline, the alteration minerals are built up of certain layer-type lattice units. The formation of any of the above alteration minerals reflects the availability of the proper basic-layer lattice unit at that particular time. Some of the necessary basic-layer lattice units became available during the destruction of the host minerals; others, particularly the brucite lattice, were formed from components introduced in solution. The more mobile elements (Na_2O, K_2O) were removed in solution.

PRACTICAL ASPECTS OF PENETRATION-RESISTANCE TESTING TO THE ENGINEERING GEOLOGIST

Eugene B. Waggoner and William A. Clevenger
Engineering Geology Branch and Earth Laboratory Branch, United States Department of the Interior, Bureau of Reclamation, Denver, Colo.

Penetration testing is an economical method of obtaining data on supporting capacities of soil foundations. Tests are accomplished by determining the driving resistance to a standard sampling

spoon using standardized methods. The engineering geologists and soils engineers of the Bureau of Reclamation work in close co-ordination in securing and interpreting penetration data for design use. Before adopting penetration testing for general use, the Reclamation Soils Laboratory completed research to determine the proper procedure for testing and to define limitations of data obtained.

The Bureau of Reclamation uses penetration testing in early-stage investigations on transmission lines, power and pumping plants, buildings, bridges, dams, etc., to aid in site selection and to obtain data for designers' use in making preliminary cost estimates. In final investigations for these structures, the penetration data are used to supplement the results of more detailed laboratory testing which is necessary for preparation of designs and specifications. For less important structures, final design may be based on penetration data alone. Some specific interesting examples of penetration testing are the foundation investigations for the Jamestown-Fargo Transmission Line towers and the Wellton-Mohawk Pumping Plants. The experiences of the Bureau of Reclamation show that penetration-test data should always be interpreted and evaluated by qualified, experienced soils engineers who blend their judgment with experience developed from observing actual structure performance and carrying out laboratory tests on various types of soils.

TECTONIC HISTORY OF THE CENTRAL ALASKA RANGE

Clyde Wahrhaftig
Alaskan Geology Branch, 4 Homewood Place, Menlo Park, Calif.

Recorded tectonic history of the central Alaska Range starts with accumulation of clastic sediments (the Birch Creek schist) in Precambrian time, of feldspathic rocks (the Totatlanika schist) in pre-Devonian time, and their subsequent deformation and metamorphism. Next events include accumulation of thick limestone and associated sediments in middle Paleozoic, metabasalts and associated sediments in Permian and Triassic, and argillaceous sediments in Jurassic and Early Cretaceous times. These rocks were deformed and intruded by granitic batholiths in Early Cretaceous time. The Cantwell formation, several thousand feet of apparently locally derived continental rocks, was deposited in Late Cretaceous time. At its top, possibly unconformably, are volcanics. It was intruded by gabbroic sills and deformed into a synclinorium in the middle of the range, where it is preserved. In the northern foothills 2000 feet of coal-bearing sediments of Eocene age accumulated in a subsiding basin. The Nenana gravel of Oligocene(?) age was shed as the detritus from rising mountains. The Oligocene(?) orogeny started in the southern part of the range and expanded northward. Most movement was essentially vertical, producing monoclines, but a zone of tight synclines lies at Polychrome Pass. A surface of late Tertiary age truncates the Oligocene(?) structures and was uplifted and tilted northward in the Pleistocene. Several exceptionally long faults and zones of deformation, with the north side commonly upthrown, parallel this part of the range; these have been intermittently active from Cretaceous time to the present.

EXTENT AND VOLUME OF CREVICES IN LIMESTONES OF MISSISSIPPIAN AGE IN THE HOPKINSVILLE QUADRANGLE OF SOUTHERN KENTUCKY

Eugene H. Walker
Ground Water Branch, U. S. Geological Survey, Geology Annex, Iowa City, Iowa

Crevices are so well developed along bedding planes and joints that four wells out of five are successful. Three-quarters of the successful wells meet water-bearing crevices before reaching a depth of 90 feet.

Data from 146 wells show even distribution of crevices to a depth of about 80 feet. Frequency declines quickly at greater depth; only 5 per cent of the crevices occur between 80 and 90 feet, and only 1 per cent between 190 and 200. Quality of water deteriorates with depth as circulation dies away; at about 145 feet half the crevices yield water of poor quality.

Crevice open space in the zone of water-table fluctuation amounts to about 0.5 per cent. Discharge of the South Fork of the Little River, during five rainless periods in the summer of 1951, was equivalent to an average of 0.067 inch per foot of decline of the water table, measured in 11 selected wells over the 46 square miles of basin. In the computations, stream discharge is assumed to represent, with small error, the amount of ground water discharged. In summer very little ground water is transpired or evaporated because the water table lies below the soil and root zone, except close to the river.

Assuming the computed ratio of crevice space to hold to a depth of 80 feet, about 4 inches of water can be stored in the aquifer, from the base of soil to 80 feet where crevices decrease and the circulation and the quality of water decline. This is roughly equivalent to the amount of water that can be stored as soil moisture.

GLACIAL TERRACES OF THE UPPER SNAKE RIVER, WYOMING-IDAHO

Eugene H. Walker
Geology Annex, University of Iowa, Iowa City, Iowa

Four terraces cut from valley trains of former ice lobes in Jackson Hole can be identified along the Snake River valley. Downstream these become lost amid the recent volcanic features of the Snake River lava plains.

A prominent terrace, which rises from 65 to 90 feet above the river in 90 miles downstream, heads at the Pinedale 1 (late Wisconsin) moraine 4 miles south of Jackson Lake. A lower terrace, about 40 feet above the river, heads at the Pinedale 2 moraine which holds in Jackson Lake, source of the Snake River. This terrace can be traced 40 miles downstream before its position becomes uncertain amid other terrace remnants. Both terraces have less slope than the 10 feet per mile average of the Snake River.

An 8–12 foot terrace is found at many places along the river.

An outwash surface 220 feet above river level begins in the Snake River canyon south of Jackson Hole. It is probably the valley train from the ice lobe (Bull Lake?-Iowan) that left morainic deposits on benches 500 feet above river level in the southern extremes of Jackson Hole. On this terrace the loess may be 35 feet thick in contrast to the few inches on the upper Pindale terrace.

Traces of still higher gravel-capped surfaces along the valley sides are too scant and scattered to permit reconstruction of old stream profiles, and erosion has destroyed any moraines to which they may have been related.

POSSIBLE REACTION AND EUTECTIC RELATIONS BETWEEN NATURALLY OCCURRING ALKALI FELDSPARS FROM THE JUDITH MOUNTAINS, MONTANA*

Stewart R. Wallace
U. S. Geological Survey, Denver Federal Center, Denver, Colo.

Rocks containing two primary alkali feldspars are rare. Recent investigations by Bowen and Tuttle of the system $NaAlSi_3O_8$-$KAlSi_4O_8$-H_2O indicate that the alkali feldspars form mixed crystals at high temperatures (in anhydrous melts), but that a sufficient pressure of water vapor will depress the solidus-liquidus curves below the solvus and result in the formation of two feldspars, first by a reaction relation and, at still higher pressures and lower temperatures, by a eutectic relation.

Vesicular and brecciated textures of intrusive alkali syenite, alkali rhyolite, and tinguaite breccia suggest that their corresponding magmas contained abundant volatiles. Albite (An_8) phenocrysts with reaction rims of potash feldspar suggest that the volatile content depressed the crystallization temperature of the feldspars to the reaction point.

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* Publication authorized by the Director, U. S. Geological Survey

Exceptionally large doubly terminated crystals of quartz in an alkali granite porphyry stock on Judith Peak are, in spite of their habit, probably low quartz and suggest growth in a fluid magma at a relatively low temperature. Silicification of the wall rock and granitization of sedimentary rock inclusions indicate an exceptionally high concentration of volatiles. Textural and size relationships of both sanidine and albite (An_5) crystals in an early fine-grained facies of the alkali granite and a later coarse-grained facies suggest simultaneous growth of both feldspars and implies a eutectic relation.

The relationship of these feldspars may illustrate in magmas both the reaction and eutectic relations between the alkali feldspars postulated by Bowen and Tuttle on the basis of their laboratory investigation of hydrous melts.

HYPOTHESES OF PATTERNED GROUND ORIGIN

A. L. Washburn
Department of Geology, Dartmouth College, Hanover, N. H.

Patterned ground—comprising mainly sorted and nonsorted varieties of circles, polygons, nets, stripes, and occurring principally in polar, subpolar, and alpine regions—is far from satisfactorily explained. Hypotheses of origin may be summarized according to dominant processes as follows: (1) ejection of stones from fines during multigelation (often-repeated freezing and thawing), (2) mass heaving, (3) local differential heaving, (4) cryostatic movement (movement by frost-generated hydrostatic pressure), (5) circulation by ice thrusting, (6) frost wedging, (7) colloidal absorption of water, (8) weathering, (9) contraction due to drying, (10) contraction due to low temperature, (11) contraction due to thawing, (12) convection due to temperature-controlled density differences, (13) convection due to moisture-controlled density differences, (14) differential thawing and eluviation, (15) artesian flow, (16) rillwork (for stripes), (17) solifluction in combination with one or more of the above processes (for stripes).

Conclusions regarding origin are that: (1) the origin of most forms of patterned ground is uncertain, (2) patterned ground is probably polygenetic, (3) climatic and terrain interpretation of patterned ground, both active and "fossil", is limited by lack of reliable data about formative processes.

With respect to future research, it is apparent that: (1) laboratory experiments, including cold-room studies specifically dealing with patterned ground, are urgently required, (2) excavations rather than surface observations should be stressed in the field, (3) engineers versed in soil mechanics and plant ecologists have much to contribute to patterned-ground research, and therefore joint work between them and geologists should produce particularly valuable results.

A^{40}-K^{40} DATING METHOD

G. J. Wasserburg and R. J. Hayden
Institute for Nuclear Studies, University of Chicago; Argonne National Laboratory, Lemont, Ill.

The radiogenic argon content of several potassium feldspars of known lead-uranium age has been determined using an isotopic dilution technique. Using a branching ratio of 0.085 and a decay constant of $\lambda = 0.55 \times 10^{-9}y^{-1}$, it was found that the calculated A^{40}/K^{40} ages could be brought into agreement with the Pb-U ages within 6 per cent. The good agreement obtained for different samples ranging in age from 260 million to 1000 million years indicates no serious loss of argon by diffusion in feldspars.

The A^{40}/K^{40} age of a sample of Beardsley meteorite, a gray chondrite, has been determined. The value obtained was 4.8×10^9 years using the above-listed constants. The determination of potassium in Beardsley was made using an isotopic dilution technique with K^{41} tracer obtained from Oak Ridge. The material was analyzed using a surface-ionization technique.

JOHN DAY FORMATION WEST OF ITS TYPE LOCALITY

Aaron C. Waters
Department of Geology, Johns Hopkins University, Baltimore, Md.

At its type locality near Picture Gorge, Oregon, the John Day formation consists of water-laid tuffs and tuffaceous clays. The basal member is a brilliant red; the upper layers are pale green to white. The red of the basal layers was caused by incorporation during deposition of particles from a thick saprolite that had developed by weathering of the underlying Clarno andesite just prior to deposition of the John Day sediments. This ancient red soil is a distinctive stratigraphic unit which has been traced far west of the type locality into the foothills of the Cascades. Locally it forms a welcome guide to the stratigraphy where lithology of the John Day is superficially similar to that of the underlying Clarno.

The John Day formation changes progressively when traced to the west. Fine-grained water-laid tuffaceous clays characteristic of the type section begin to alternate with increasing amounts of air-deposited pumice-lapilli tuffs and coarse rhyolite breccias, and especially with great volumes of welded tufi and sintered tuff. Large domes and thick flows of platy rhyolite and perlite vitrophyre also appear.

The vents through which these rhyolite pyroclastics and lavas reached the surface are magnificiently exposed, especially in the Burnt Ranch, Eagle Rock, and Ashwood areas. Both dikes and central vents are abundant. The welded tuffs appear to have been produced by relatively quiet fissure eruptions, not by strong Peleean explosions.

KANSAN TILL AND A PRO-KANSAN LOESS FAUNULE FROM INDIANA*

William J. Wayne
Indiana Geological Survey, Indiana University, Bloomington, Ind.

Several exposures of till with a 9- to 11-foot-thick leached zone and overlain by calcareous Illinoian till have been discovered recently in southwestern Indiana. Although the presence of pre-Illinoian drift has long been inferred, these exposures afford the first proof of such a drift in the State. Because of the thick weathered zone and the presence of Kansan drift in southern Illinois, this till is regarded as Kansan. The distribution of exposures and thickness of till indicate that a Kansan glacier probably covered nearly as much of southwestern Indiana as did the Illinoian ice.

Three feet of fossiliferous, pro-Kansan loess underlies calcareous Kansan till in an exposure in the spillway for Cagles Mill Reservoir, Putnam County. A small bulk sample from this loess yielded 168 specimens of terrestrial gastropods. The species and the number of individuals of each found in the sample are: *Carychium exile canadense* (7), *Cionella lubrica* (2), *Columella edentula* (4), *Discus cronkheiti catskillensis* (22), *Econulus* cf. *chersinus* (3), *E. fulvus* (6), *Gastrocopta armifera* (6), *Hendersonia occulta* (18), *Pupilla muscorum* (1), *Retinella electrina* (3), *Stenotrema fraternum* (11), *Strobilops labyrinthica* (35), *Succinea avara* (21), *S. grosvenori* (14), *Vertigo bollesiana* (4), *V. elatior* (11). Seven of the 16 species in this faunule are not known from the living Indiana fauna; none are extinct in North America, however.

TECTONIC HISTORY OF THE NORTHERN BOULDER BATHOLITH REGION, MONTANA

R. A. Weeks and M. R. Klepper
U. S. Geological Survey, Spokane, Wash.; U. S. Geological Survey, Washington, D. C.

The northern Boulder batholith region was relatively stable from Belt time through Early Cretaceous time, and about 11,000 feet of dominantly marine sedimentary rocks accumulated.

* Published with permission of the State Geologist, Indiana Geological Survey

Volcanism began in Late Cretaceous (Niobrara) time, and more than 4000 feet of andesitic pyroclastics and flows accumulated. Age of the uppermost volcanic rocks is unknown, but a flora of probable Judith River age occurs several hundred feet below the top of the preserved sequence. Volcanism was accompanied by diorite porphyry intrusions and local folding. Major folding and local thrust faulting followed, culminating in emplacement of the batholith. An average age of 68 million years determined for monazites and zircons from batholith rocks indicates a very late Cretaceous or very early Tertiary age for the batholith.

Uplift and erosion during Paleocene and Eocene time resulted in a mountainous terrane and partial unroofing of the batholith. Oligocene gravel and rhyolitic sediments accumulated in subsiding intermontane basins; elsewhere rhyolitic tuffs and flows accumulated on a high-level erosion surface. Dacitic volcanic rocks, contemporaneous with or slightly younger than the rhyolites, are preserved in basins, smaller valleys, and fault blocks. At least two periods of hydrothermal mineralization are recognized: following emplacement of the batholith and following extrusion of the younger volcanic rocks.

Tilting of Oligocene basin deposits, partly associated with movement on range-front faults, preceded deposition of stream gravels of Miocene and Pliocene age. Pediments formed in late Tertiary to Pleistocene(?) time. Continuing movement on some faults is indicated by modern earthquakes.

X-RAY-DIFFRACTOMETER THERMAL STUDIES OF CLAY-MINERAL DEHYDROXYLATION

E. J. Weiss and Richards A. Rowland

Department of Ceramic Engineering, The University of Texas; Exploration and Production Research Division, Shell Development Company, Houston, Texas

With an oscillation-heating x-ray-diffraction technique the position and intensity of an x-ray diffraction maximum may be followed continuously while a powdered sample is heated at a regular rate of temperature rise (5°C per minute). The sample is sedimented on a platinum slide mounted in a furnace designed to fit the horizontal shaft of the North American Phillips X-ray Diffractometer. The diffractometer is set with the maximum to be followed at the center of a one-half degree 2θ oscillation. After heating and oscillating the tops of the recorded series of peaks indicate position and intensity. The bottoms represent the background which is very sensitive to position changes.

Typical oscillation-heating patterns of basal spacing maxima for Georgia kaolinite, a Vermont chlorite, a clinochlore, and sheridanite are presented. The kaolinite (001) remains constant at 12.5 2θ until it collapses at 525°C. The chlorites (002) shift from 12.51° 2θ to 12.47° 2θ and begin to collapse simultaneously with the intensity increase of the (001).

Sheridanite (001) increases abruptly at 525°C and collapses at 750°C after shifting from 6.28° to 6.49° 2θ. Clinochlore follows a similar pattern. The (002) collapses abruptly at 525°C. Vermont chlorite (001) begins the intensity increase at 500°C, is greatest at 640°C, begins to collapse at 740°C, and is collapsed at 810°C after shifting from 6.28° 2θ to 6.52° 2θ. The (002) collapse begins at 500°C and is complete at 810°C. These differences may be related to the iron content of the brucite layer.

AGE AND RELATIONSHIPS OF THE ANCESTRAL CROCODILE *PROTOSUCHUS*

S. P. Welles

Museum of Paleontology, University of California, Berkeley, Calif.

The earliest reptiles classified as Crocodilia are *Pedeticosaruus* and *Notochampsa* from the Upper Triassic Cave ss. of S. Africa, and *Erythrochampsa*[1] from the underlying Red Beds. *Pedeticosarus* is aberrantly bipedal, with elongate hind limbs, and, although it possesses elongate carpals, it retains

a primitive antorbital vacuity and is not related to later crocodiles. *Notochampsa* is closely allied to *Erythrochampsa*, and both are good ancestral crocodiles although the greatly expandeds capula is aberrant. In its skull and skeletal features, *Protosuchus* from the Dinosaur Canyon s.s (Colbert and Mook, 1951, Bull. Am. Mus. Nat. Hist., vol. 97) [Orange Red ss.] of N. Arizona, is considerably more crocodilian than these Upper Triassic forms and is more closely comparable with *Alligatorellus* and *Alligatorium* of the Upper Jurassic of France, or with *Amphicotylus* of the Morrison of Colorado.

Protosuchus can therefore be interpreted as indicative of at most a Lower Jurassic age, and this is in accordance with a similar age determination based upon the carniverous dinosaur *Megalosaurus wetherilli* from the same region but from 34 feet higher above the Chinle and in a shaly lithology of Kayenta type.

AGE OF THE KEYENTA FORMATION

S. P. Welles
Museum of Paleontology, University of California, Berkeley, Calif.

Overlying the Chinle formation in the Painted Desert of Arizona is a series of variegated but dominantly red sandstones and mudstones. These have been referred to in whole or in part under such names as Todilto formation, Kayenta formation, Orange red sandstone, Chinle A, and Dinosaur Canyon sandstone. They contain invertebrates which are not diagnostic of the age of the rocks; fish that have been identified as Triassic; a crocodile that has been considered either Triassic or Jurassic; dinosaur tracks thought to be younger than those of the Connecticut Valley; and a new carnivorous dinosaur, *Megalosaurus wetherilli* Welles, 1954 (Bull. Geol. Soc. Am., vol. 65). The dinosaur was collected in mudstones (?Kayenta) 126 feet above the Chinle, while the crocodile, *Protosuchus richardsoni* (Brown) came from medium sandstones (Orange Red sandstone, or Dinosaur Canyon sandstone) 92 feet above the Chinle.

The indices derived from measurements of fore and hind limb bones indicate that the dinosaur is closest to *Megalosaurus bucklandi* Meyer of the Middle Jurassic and is considerably advanced over the Keuper carnosaurs. The development of the dorsal process of the tibiale is similarly more advanced than in Triassic forms.

It is therefore suggested that the dinosaur-bearing rocks are Lower Jurassic or possibly Middle Jurassic at this locality.

ACTIVE TRANSCURRENT FAULTING IN NEW ZEALAND

H. W. Wellman
N. Zealand Geological Survey

Within the New Zealand region the Circum-Pacific Mobile Belt extends through the west side of the South Island and the east side of the North Island to include the high mountains, the strongly folded Tertiary sediments, and the transcurrent faults. The major transcurrent faults strike northeast, and all show dextral displacement. They interrupt all topographic features except flood plains and are conspicuous features. Recently displaced terraces have been matched, and the faults proved to be transcurrent. The oldest low-level terrace, probably last-glacial, is displaced 100 to 300 feet horizontally and 10 to 50 feet vertically. This and younger terraces are displaced in proportion to their height above river level, suggesting that faulting and river downcutting have proceeded at an average uniform rate at least for the last 10,000 years. The displacement of high-level terraces has been measured at a few places; the largest definite horizontal displacement is 2300 feet. The suggested 300-mile Alpine fault displacement is probably post-Jurassic and gives a displacement rate similar to that determined from the last glacial terrace.

STRATIGRAPHY AND ARCHAEOLOGY OF THE SCHARBAUER SITE, MIDLAND, TEXAS

Fred Wendorf and Claude C. Albritton, Jr.
Museum of New Mexico, Santa Fe, N. M.; Southern Methodist University, Dallas, Texas

At the Scharbauer site, 6 miles southwest of Midland, a sequence of lacustrine and aeolian deposits of Quaternary age comprises the following units, named in ascending order: (1) 5 feet of lacustrine calcareous sandstone containing shells of pond snails and bones of horse, turtle, camel, bison, dire wolf, peccay, prairie dog, and llama; (2) 0–5 feet of gray calcareous sand containing horse bones; (3) 0–16 feet of largely aeolian brownish sand containing bones of horse, bison, and turtle, with an incipient soil zone locally preserved at the top; (4) 0–16 feet of brownish sand forming irregular dunes stabilized by vegetation; and (5) 0–30 feet of tan sand forming active dunes. The five units are separated by disconformities.

Associated archaeological material consists of a fragmentary human skeleton found on the surface of and slightly buried in the sand of unit 2; and a large series of Folsom and related early-style projectile points as well as more recent lithic material from the surface of unit 3. Chemical analyses (including fluorine) of the human and associated faunal remains indicate that the human skeleton is of approximately the same age as the extinct fauna found in unit 2.

SALT-WATER ENCROACHMENT AS INDUCED BY SEA-LEVEL EXCAVATION ON ANGULAR ISLAND, PALAU

Chester K. Wentworth, Arnold C. Mason, and Dan A. Davis
U. S. Geological Survey, Volcano Observatory, Hawaii National Park, Hawaii; University of Illinois, Urbana, Ill.; U. S. Geological Survey, Honolulu, T. H.

Angular, southwesternmost of the Palau Islands, 800 miles southwest of Guam, has an area of 3.2 square miles and consists of reef limestone of Pleistocene and Recent age. In the northwestern part of the island a basin is formed by a ringlike ridge that has a maximum altitude of 150 feet. To the east and south a series of arc-shaped lower ridges and intervening depressions are concentric with the ridge. Beyond these, a low plain with shallow swales comprises the remaining two-thirds of the island. The ridges are composed of indurated limestone, whereas the plain is underlain chiefly by unconsolidated coralline fragments.

Phosphate has been mined from the three types of topographic depressions since 1908. When power equipment was introduced, excavations were extended below sea level. Lakes formed in these excavations and, despite an annual rainfall of 110 inches, contamination of fresh-water supplies and of agricultural land by salt water resulted from tidal pulsations through the fissured rock. Stoppage of mining was imminent unless remedial measures could be devised.

Angaur provides a model of the operations of a Ghyben-Herzberg fresh-water lens on an oceanic island. At numerous lakes, wells, and test holes, continuing observations were made on water levels; amplitude and lag of tidal fluctuations; and mineral content, pH, and temperature of the lens. These observations guided the selection of constantly adjusted remedial measures, which included partitioning of lakes, and bottom filling or back filling of compartments that failed to freshen because of connecting fissures.

FOUNDATION PROBLEMS ASSOCIATED WITH THE TERMINAL ISLAND SUBSIDENCE, CALIFORNIA

Philip J. West
Southern California Edison Company, 601 West Fifth St., Los Angeles, Calif.

The Wilmington Oilfield, California, containing oil-bearing Miocene and Pliocene sands, siltstones, and shales, has subsided continuously since initial development of the field in 1938. The elliptically shaped subsidence trough occupies an area about 8 miles long by 3 miles wide. The present rate of

sinking is 1½ feet per year, or about half a foot per year less than the maximum rate, which occurred in 1951. At the center of the subsidence trough the ground surface has been depressed approximately 19 feet. Within the zone of subsidence horizontal contraction of the ground surface has amounted to as much as 4¾ inches per 100 feet.

In the industrially developed Terminal Island-Long Beach Harbor region the horizontal earth movements have imparted large stresses to physical structures. Where distortion or failure of structures, or the threatened inundation by sea water has become apparent, remedial construction has been necessary.

At the 425,000 KW capacity Long Beach Steam Station of the Southern California Edison Company, located near the subsidence center on the eastern end of Terminal Island, much remedial construction has been completed. Condenser cooling-water tunnels, fractured by earth shortening, have been replaced by above-ground conduits with articulated joints. Compression joints have been built into yard utility pipe lines, and an impervious earth-fill protective dike has been raised.

Current investigations of earth movement include extensive surveys of physical structures. Horizontal soil movements relative to sidewalls of substructures and foundation piles are being determined by in-hole surveys of plastic-cased wells.

ANALYSIS AND CLASSIFICATION OF STRATIGRAPHIC UNITS

Harry E. Wheeler and V. Standish Mallory
Department of Geology, University of Washington, Seattle, Wash.

Rocks may be stratigraphically allocated on the basis of a potentially large number of conceptually different criteria. The most commonly employed of these are *lithostratigraphic*, *biostratigraphic*, and *time-stratigraphic*.

Stratigraphic entities based on each of these primary kinds of criteria may be *vertically*, *laterally*, and *vertico-laterally* segregated into corresponding categories of *secondary* rank.

Each secondary category may be represented by specific units which are either *formal* (those given proper names) or *nonformal* (unnamed) or both. Of these three factors in classification, formalization is of least importance. Precedent demonstrates that *any* specific stratal unit may be formalized when application of a proper name is deemed useful. Thus, lithostratigraphic successions, for example, may be vertically segregated into formal specific units such as *groups*, *formations*, *members*, *etc.*, and nonformal *"lithotopes," tongues*, *beds*, *etc.*; they may be laterally segregated into formal or nonformal *lithofacies*; or they may be vertico-laterally segregated into formal or nonformal *lithosomes*. Although only vertically segregated lithic units have been regarded as "rock units" in the past, it is evident that all lithic units, regardless of mode of segregation, are rock-stratigraphic. Thus, lithofacies and lithosomes are also rock units.

Time-rock and so-called geologic time units (*system-period*, *series-epoch*, *stage-age*) are time-stratigraphic in concept; *e.g.*, the term Triassic Period implies Triassic System, neither of which has a geologic connotation without integration with rocks. Thus the time-rock element of classification has a logical category for time-stratigraphic units only, and none for *pure* time units.

CONSOLIDATION OF THE CONTINENTS

Robert R. Wheeler
3140 Amherst St., Dallas, Texas

The compressive mechanism responsible for crustal shortening in the continents is elucidated by the following convincing arguments: (1) most of the evidence requires a cooling shrinking earth (Umbgrove, 1951); (2) the oceanic crust, being denser and stronger than continental sial, exerts compression upon the continental borders as the earth shrinks (Jeffreys, 1952) and (3) reverse faults,

extending to the subcrust some 400 miles beneath the continents and island arcs, localize current semismicity, volcanism, and crustal warping (Benioff, 1954).

This compression explains the history and pattern of continental deformation commencing with immobilization of shields and outlying nodes in Precambrian time, later bordered by midcontinental basins and marginal geosynclines of transitory mobility, culminating in orogeny and varying degrees of stabilization. Crustal shortening was generally directed away from the Atlantic and Gulf until late Paleozoic stabilization; thence compression was diverted to less deformed, more mobile regions bordering the Pacific during Mesozoic and Cenozoic time.

Such consolidation involves substantial reduction of the continental areas with proportionate thickening of the sialic crust, or, conversely, the continents initially occupied a considerably larger portion of the earth's surface. Shrinkage and reduced global area, being at the expense of the continents, indicates that oceanic area and sea volume remain constant while the thickened continents, though buoyed higher, tend to be reduced to sea level by accelerated erosion and shelf deposition.

SANCTITY OF SEA LEVEL

Robert R. Wheeler
3140 Amherst St., Dallas, Texas

"What is so sacrosanct about current sea level?" inquired K. K. Landes (G.S.A., 1952), in view of . . . "evidence such as marine strata of a sea level rise above present datum of 25,000 feet. . ."

Of course marine deposits at mountainous heights and their time equivalents deep in adjoining basins reflect crustal movements, not changes in sea level. It is suggested that the littoral deposits of widespread early Paleozoic seas, for example the Potsdam sandstone of the St. Lawrence Valley, lapping out upon the southeastern flank of the Canadian Shield (immobilized in Precambrian time), constitutes a datum approximating pre-glacial sea level, with which present and past fluctuations of the sea may be compared.

Granting that the thick, conformable, geosynclinal sequences wedge out toward the Shield (and nodes of Precambrian stabilization peripheral to it) does not imply great reductions of sea level, nor could great elevations of the sea occur without leaving a sedimentary record across the Shield. Instead troughs and basins of transitory mobility subsided rapidly relative to a fairly constant sea level and were ultimately stabilized by orogeny, leaving most or all of the deformed region above sea level.

Late Paleozoic and Pleistocene reductions of sea level, by impounding of sea water during glacial epochs, were exceptional nontectonic instances of exposure of the continents. Otherwise, regional variations of crustal mobility may account for the distribution of Cambrian to Recent sediments more logically than assuming large-scale fluctuations of sea level or wholesale (epiorogenic) submergence and emergence of the continents.

HYDROTHERMAL ALTERATION AND OTHER CHARACTERISTICS OF FIVE EXPLORED HOT-SPRING SYSTEMS*

Donald E. White
U. S. Geological Survey, Menlo Park, Calif.

Hydrothermal alteration of five explored hot-spring systems has been studied. Four systems—the Upper Basin and Norris Basin of Yellowstone Park; Steamboat Springs, Nevada; and Wairakei, New Zealand—are relatively high in temperature near surface and at depth and are of the volcanic type.

Superficial acid leaching occurs in three of the four areas. Deep alteration minerals include

* Publication authorized by the Director, U. S. Geological Survey

adularia, illite, montmorillonite, pyrite, chlorite, calcite, zeolites, kaolinite, and sodic feldspar. All have been found at Steamboat Springs; most were described from the Upper Basin and Wairakei; but only a few occur at Norris Basin. Fresh rock may occur near the surface but is less common at depth.

Chalcedony, quartz, and calcite are typical vein minerals; opal is dominant near the surface but does not occur below 100 feet. Cinnabar and stibnite occur at Steamboat, and orpiment and realgar in Norris Basin, but all seem to be restricted to shallow depths. Sinter at Steamboat and Wairakei contains gold and silver.

In some respects the four high-temperature spring systems are similar to epithermal gold-silver deposits.

The fifth system—Sulphur Bank, California—is the only one that has been mined extensively for its metal content (quicksilver). Rock alteration and present temperatures differ notably from those of the other systems. Most alteration is of the superficial acid type, but minor replacement calcite, pyrite, and argillic minerals occur in deeper workings. Cinnabar and opal persist to depths of at least 260 feet. A volcanic source for the ores and thermal waters is not yet certain.

STRUCTURE OF LOPOLITHS

H. D. B. Wilson
Department of Geology, University of Manitoba, Winnipeg, Manitoba, Canada

Field studies of five large differentiated lopolithic intrusives show that they possess many similar features. The bottoms of the intrusives are not parallel to the layering but in general dip more steeply toward the center. The layer in contact with the footwall rocks is, therefore, only the bottom layer at that particular locality. The bottoms of the intrusives are irregular and may abruptly deepen or shallow as much as several thousand feet so that additional deeper layers may be revealed by the deepening, or the deeper layers may be cut out by the shallowing. Any particular section of a lopolith reveals only a portion of the layers so that the average composition cannot be determined from outcrops. Corresponding patterns may be found in the layering of the Sudbury, Bushveld, and Great Dyke intrusives. The layers in part of the Bushveld intrusive have undergone internal dislocations not reflected in the wall rocks.

The lopoliths, including the Sudbury intrusive, are interpreted as being funnel-shaped in cross section with the most basic rocks in the lower portion of the funnel.

The upper portion of the lopoliths may be similar to some batholithic granites, and the overlying roof rocks display mountain-folded structures in contrast to the lack of such structures in the gently warped formations beneath the lopoliths.

MIOCENE CARNIVORES, TEXAS COASTAL PLAIN

John Andrew Wilson
Department of Geology, University of Texas, Austin, Texas

Fragmentary specimens of lower, middle, and upper Miocene carnivores furnish additional evidence for establishing the ages of the vertebrate-bearing biostratigraphic units of the Texas Coastal Plain. *Tomarctus scitulus*, *Daphaenodon* c.f. *superbus*, and *Amphicyon* sp. have been identified in the Garvin Gully local fauna, upper Arikareean age, of central Texas, Oakville formation. *Tomarctus canavus* has been identified in the Burkeville fauna, early Hemingfordian age, of east Texas, Fleming formation. *Amphicyon* sp., *Aelurodon francisi*, and ? *Agriotherium* sp. are known from the Cold Spring fauna, late Hemingfordian age, of east Texas, Fleming formation. *Amphicyon* sp. and *Aelurodon taxoides* are present in the Goliad fauna, late Barstovian age, from the Lapara sand member of the Goliad formation, southwest Texas.

The greater depth of the lower jaw of *Aelurodon francisi* seems to confirm its affinities with *Aelurodon* rather than with *Tomarctus*.

ENGINEERING GEOLOGY OF THE BALDWIN HILLS RESERVOIR SITE, CALIFORNIA

R. R. Wilson and D. G. Campbell
Los Angeles Dept. of Water and Power, Box 3669 Terminal Annex, Los Angeles, Calif.

The Baldwin Hills Reservoir Site, 7 miles southwest of the Los Angeles City Hall in Pliocene and Quaternary sediments, was the only available site which met the required engineering specifications. Construction was started in 1947 and completed in 1951.

Excavation uncovered a zone of late Pleistocene or Recent normal faults trending north, dipping west, and having a total apparent vertical displacement of approximately 60 feet. This zone, which appears to be part of the active Inglewood fault system, would have passed through the original gate-tower site at subgrade elevation. A relocation of the gate tower was made.

Early in the construction a slide developed in the east abutment of the dam 350 feet downstream from the axis. It consisted of approximately 25,000 cubic yards of soft siltstone having an average moisture content of 28 per cent. The sliding surface was a gently dipping 3-inch clay bed. Movement reached a maximum of 0.11 foot per day and was stopped within 17 days of its inception by unloading of the slide. The slide was probably due to excavation in the toe of the abutment.

LOCALIZATION OF URANIUM MINERALS IN CHANNEL SEDIMENTS AT THE BASE OF THE SHINARUMP CONGLOMERATE, MONUMENT VALLEY, ARIZONA

Irving J. Witkind
U. S. Geological Survey, Denver Federal Center, Denver, Colo.

During the summers of 1951 and 1952 the U. S. Geological Survey mapped the geology and uranium deposits in three 15-minute quadrangles on the Navajo Indian Reservation in Apache and Navajo counties, northeastern Arizona. Ages of exposed sedimentary rocks range from Permian, represented by the Halgaito tongue of the Cutler formation, to Jurassic, represented by the Salt Wash member of the Morrison formation. The dominant structural element of the area is the Monument upwarp, a large asymmetrical anticline whose northern end is near the junction of the Green and Colorado rivers in Utah and whose southern end is near Kayenta, Arizona. North-trending subsidiary asymmetrical anticlines are superimposed on the upwarp.

Uranium ore bodies are localized in the conglomeratic sandstone of the Shinarump conglomerate (Triassic) that fills channels scoured in the underlying Moenkopi formation (Triassic). These channels range in cross section from 15 feet wide and 10 feet deep to 2300 feet wide and 70 feet deep. Fragments of trees were deposited with Shinarump sediments in the channels. It is suggested that when the Shinarump conglomerate was invaded by mineralizing solutions they deposited the uranium ore mainly in places where decomposing plant material had been. It is also suggested that short channels are more likely to contain ore than long channels.

BLISTER HYPOTHESIS AND ECONOMIC GEOLOGY

C. W. Wolfe
725 Commonwealth Ave. Boston, Mass.

The origins and peculiarities of hydrothermal solutions are readily explained by differential solution or by complete anatexis of previously existing rock under the thermal influence of a Blister area. The unique character of the rocks subjected to partial or complete magmatization determines the nature of the hydrothermal solutions which are generated by Blister heat.

Throughout geological time several processes have separated the ore metals into distinct spatial positions. If we presuppose an early magmatic earth, magmatic differentiation took place with the forming of the first crust and has recurred in every magmatic phase since that time. Weathering, in

itself, is a profound agent of separation; witness iron, gold, and other deposits. Sedimentary transfer again results in variation of mineral and metallic concentration, as is well known. Sedimentation produces a similar effect, the mechanical aspects of which are well understood. More is to be learned concerning chemical precipitation and sedimentation, but we are already well aware of the concentration of uranium, manganese, lead and zinc, and other metals in particular sedimentary environments.

If any one of these unique concentrations is then affected by Blister heat, partial or complete metamorphism or magmatization will take place; unique hydrothermal solutions will form; and distinctive metallogenetic provinces will result. It would seem, then, that a proper study of ore deposits begins, not with magmas and the solutions derived therefrom but with the nature of the rocks from which the magmas and the hydrothermal solutions were derived.

HARDNESS DETERMINATIONS ON SILICON, GERMANIUM, AND THE III-V COMPOUNDS

G. Wolff, L. Toman, Jr., N. J. Field, J. Broder
Chemical Physics Branch, Squier Signal Laboratory, Fort Monmouth, N. J.

Micro-indentation hardness measurements have been made on certain substances with diamond and sphalerite type structures using a Knoop-type diamond indenter. The investigation, performed mainly on {111} planes (or $\{1\bar{1}1\}$ planes), showed differences in hardness for different directions and, to a lesser extent, for different areas. Since the hardness varied slightly for identical crystallographic directions and localized areas, the data were evaluated statistically. The plots of the indentation values for all substances investigated gave straight lines on probability paper. This indicates a normal Gaussian distribution of the data. The Knoop hardness values, derived from $H = CL/l^2$ (C—constant, L—load applied to indenter, l—length of indentation), range from 83 to 190 (Mohs values from 2½ to 5) for the III–V compounds (InSb, InAs, InP, GaSb, GaAs, GaP, AlSb, AlAs), and from 268 to 547 (Mohs values from 4½ to 6) for germanium and silicon. These values are roughly proportional to r^{-3}, where r is the interatomic distance.

ALMANDITE GARNET STABILITY RANGE

Hatten S. Yoder, Jr.
Geophysical Laboratory, 2801 Upton St., N. W., Washington, D. C.

The upper thermal stability limit of almandite garnet, $Fe_3Al_2Si_3O_{12}$, has been determined up to 10,000 bars water vapor pressure. The univariant equilibrium curve for the reaction

$$5 \text{ almandite} \rightleftharpoons 2 \text{ iron-cordierite} + 5 \text{ fayalite} + \text{hercynite}$$

passes through the points 1030°C—10,000 bars; 980°C—8000 bars; 930°C—6000 bars; 880°C—4000 bars; and 830°C—2000 bars. A projection of this curve indicates that almandite would be stable below 785°C at atmospheric pressure.

The synthetic almandite crystals are cinnamon brown and exhibit the dodecahedral and icositetrahedral forms usually, and the cube and octahedron rarely. They are optically isotropic with $n = 1.830 \pm 0.003$ in sodium light. The powder x-ray diffraction pattern is identical with that of a natural almandite close to the ideal composition and has $a_0 = 11.53 \pm 0.01$ Å.

Growth is obtained from glass ($n = 1.662$) of the requisite composition and a mix consisting of ferrous oxalate dihydrate, gamma alumina, and silica glass. Complete reaction is obtained in less than 2 hours at the highest pressures and temperatures, and the rate of reaction falls off rapidly below 7000 bars to nil at 1000 bars. Oxidation of the breakdown products to magnetite + quartz + hercynite, magnetite + iron-cordierite + hercynite, or to magnetite + quartz + corundum is common.

The occurrence of almandite in the metamorphic rocks as well as in some igneous rocks is accounted for by the character of the stability curve. The behavior of these garnets in the "wet" and "dry" contact aureoles can also be interpreted from the experimental data.

TRACE ELEMENTS IN RECENT MARINE SEDIMENTS

Edward J. Young
U. S. Geological Survey, Bldg. 213, Naval Gun Factory, Washington, D. C.

Trace-element distribution of 96 samples of Recent marine sediments and some geologically older sediments was studied spectrographically using $PdCl_2$ as an internal standard. V, Ti, Zr, Co, Ni, Sc, Cr, and La were analyzed quantitatively, and Ba and Sr semiquantitatively. Samples were run in duplicate, and precision—expressed as standard deviation—ranged from 5 per cent for Co_3O_4 to 14 per cent for ZrO_2. Working curves were based on standard granite G1 and standard diabase W1. A selection of average results is listed and compared with an average igneous rock.

Oxide	*Percentage in red clay, average of 20 samples*	*Percentage in near-shore sediments, average of 29 samples*	*Percentage in average igneous rock*
ZrO_2	0.023	0.030	0.020
TiO_2	0.70	0.67	0.73
V_2O_5	0.026	0.023	0.022
Cr_2O_3	0.012	0.012	0.0146
NiO	0.033	0.006	0.010
Co_2O_3	0.0138	0.0016	0.0028
Sc_2O_3	0.0048	0.0021	0.0031
La_2O_3	0.026	0.011	0.0053
SrO	0.07	0.035	0.026
BaO	0.9	0.17	0.11

The similar amounts of Zr, Ti, V, and Cr in oceanic red clay, near-shore sediments, and the average igneous rock indicate a terrigenous origin for red clay rather than one involving the submarine weathering of volcanic rock. The large enrichment of Ni and Co in red clay may be explained by accretion of meteoritic matter and coprecipitation or scavenging. Although the average BaO content of red clay is unusually high, BaO is unequally distributed in red clay and ranges from 0.1 to over 2.0 per cent. This wide variation is thought to be caused by oceanographic factors affecting the solubility of Ba salts in sea water.

FACTORS INFLUENCING THE ARTIFICIAL PRECIPITATION OF CALCIUM CARBONATE

Edward J. Zeller and John L. Wray
Department of Chemistry, University of Wisconsin, Madison, Wisc.

Aragonite, calcite, and vaterite have been precipitated under conditions of controlled temperature, pH, and impurity ion concentration. Results from x-ray diffraction studies, spectrographic analysis, microscopic examination, and thermoluminescence studies have provided information regarding the extent to which these three factors affect the formation of the various crystalline forms. $CaCO_3$ precipitates were made from dilute solutions of $Ca(NO_3)_2$ by the controlled addition of dilute Na_2CO_3.

Employing this method of precipitation, high pH, high concentrations of Pb^{++}, Sr^{++}, Ba^{++}, low concentrations of Mg^{++}, and a temperature range from 50° to 65°C appear to favor aragonite formation. However, aragonite was produced at temperatures outside this favorable range when conditions of high pH and favorable impurity concentration existed. Calcite and vaterite have been obtained

throughout a wide temperature range. Calcite formation is favored by a lower pH, low concentrations of Pb^{++}, Sr^{++}, Ba^{++}, and high concentrations of Mg^{++}; pH and impurity effects cannot easily be correlated directly with the synthesis of vaterite.

The pH and impurity effects are closely related and appear to be significant factors influencing the crystalline form of $CaCO_3$. Temperature appears to influence the crystalline form of the precipitate primarily through its effects upon pH and the solubility of the impurity ions. The conclusion that impurities are the controlling factors determining the crystalline form of $CaCO_3$ under conditions of constant temperature is supported by evidence obtained from spectrographic studies of natural cave formations.

GEOLOGIC FACTORS CONTROLLING INTEGRATION OF FLOOD CONTROL AND WATER CONSERVATION PROGRAMS IN LOS ANGELES COUNTY, CALIFORNIA

Edward J. Zielbauer
Los Angeles County Flood Control District, 2250 Alcazar St., Los Angeles, Calif.

Physiographic and climatic factors in the rugged San Gabriel Mountains, with their sheared and intensely weathered rocks, are conducive to very high-intensity rains and to high-velocity canyon flows bulked with debris. Concentrations of flood runoff occur within minutes rather than hours or days. Flood-control structures must prevent disastrous floods and conserve, in this semiarid region, all economically salvable storm flow. Flood-control and water-conservation programs are integrated at 14 major flood-regulating and storage dams, 29 debris basins, 3 flood-regulating basins, and 2300 acres of off-channel spreading grounds.

Examples of the adaptation of installations to geologic controls include: (1) *Dams:* (a) San Gabriel—Proximity to earth slips and faults necessitated revision from concrete to rock-fill type dam. Depth of weathering required further revision from rock fill to combination compacted earth and rock fill. (b) Tujunga—Terrace gravels and fanglomerate capping granodiorite bedrock necessitated cut-off wall construction and an earth-fill blanket. (2) *Debris basins:* Dunsmuir—70% slopes, 30% stream gradient, weathered rock, canyon landslides and high rainfall intensities determined 100,000 c. y./sq. mi. design capacity to effectively desilt outlet flows. (3) *Recharge sites:* Hansen Spreading Grounds—Location was determined by feasibility of recharging San Fernando ground-water basin from controlled releases on Tujunga alluvial cone.

Hydraulic continuity of intermontane valley fill with Recent and Pleistocene coastal aquifers permits the integrated programs effectively to recharge ground-water basins having a storage capacity exceeding 2,000,000 acre-feet.

ABSTRACTS OF PAPERS SUBMITTED FOR THE APRIL MEETING IN SEATTLE, WASHINGTON, MARCH 26–27, 1954

PLUVIAL LAKE LEVELS OF SOUTH-CENTRAL OREGON

Ira S. Allison

Oregon State College, Corvallis, Ore.

Detailed measurements of the profiles of the shores of the former pluvial lakes in the interconnected Summer Lake-Chewaucan Marsh-Abert Lake fault troughs of south-central Oregon reveal a series of pluvial-lake shore lines which indicate a long and complicated history.

The principal beach ridges (or slightly lower wave-eroded niches) in the Summer Lake basin stand at elevations (in round numbers) of 4190, 4225, 4280, 4325–4350 (a swarm), 4365–4370, 4400, 4455, 4470, 4485, and 4520 feet above sea level. Other minor ones occur at intermediate levels. The level of modern Summer Lake varies but is about 4150 feet.

The 4190-foot beach is assigned to Antevs' "Little Pluvial." A concentration of pumice sand between 4260 and 4280 feet apparently dates the corresponding lake level at the time of the eruption of Mount Mazama (Crater Lake) 6450 years ago, as the volcanic ash is interbedded in other lake sediments at lower elevations. The 4370- and 4400-foot levels are especially well marked and appear to denote major pluvial substages or possibly stages. At least some of the higher shore lines are thought to be pre-Wisconsin.

At its highest levels a single lake occupied the interlocked fault troughs, but below the 4390-foot level Summer Lake basin proper and the Chewaucan-Abert basin held two separate lakes, which after the division stood at different levels.

RADIOACTIVITY IN THE NORTHWEST

Frank C. Armstrong

U. S. Geological Survey, Spokane, Wash.

The Geological Survey on behalf of the Atomic Energy Commission is searching for uranium in the four northwestern States. To investigate this large area adequately, the Survey needs the active interest of the prospecting public. The Spokane office of the Survey will assist in this work by testing and assaying samples submitted by the public.

Sedimentary uranium-bearing deposits in Idaho are the euxenite-samarskite placers of central Idaho and the phosphate-rich beds of the Phosphoria formation. Pitchblende has been found in veins at the Garm-Lamoreaux mine northwest of North Fork, Idaho, and in the Coeur d'Alene mining district. In Montana, uranium occurs in the Phosphoria formation and in quartz-sulfide and chalcedonic quartz veins in the Boulder batholith. Radioactivity has been detected in the Quartzburg district, Oregon, and secondary uranium minerals are reported from southernmost Oregon. Pitchblende occurs north of Davenport, Washington, and is reported from a few places in the northern Cascade Mountains.

Uranium is widespread, but the geology of its occurrence is not well known. Any rock type with the possible exception of pegmatites and unmineralized ultrabasic plutonic rocks may contain economic concentrations of uranium, and even pegmatites have yielded small amounts of uranium ore in Madagascar.

Two areas in the Northwest especially worthy of prospecting are the northern Cascade Mountains and central and eastern Montana.

EFFECT OF ORGANIC DECOMPOSITION ON THE $CaCO_3$ CONTENT OF MARINE SEDIMENTS

Richard G. Bader
Dept. of Oceanography, University of Washington, Seattle, Wash.

The $CaCO_3$ composition of some near-shore marine sediments indicates that there is a relationship between the supply from the bottom-dwelling shell-bearing fauna and the processes of organic decomposition. Apparently the $CaCO_3$ may accumulate in regions where the faunal population is extremely low and be depleted from the sediments in those areas of high population. The amount of organic decomposition is related to this distribution of $CaCO_3$; regions of high decomposition have low $CaCO_3$ contents.

SOME PROBLEMS IN LAYING A SUBMARINE POWER LINE

Clifford A. Barnes
Dept. of Oceanography, Univ. of Washington, Seattle 5, Wash.

Small-diameter submarine lines have long been used for communications. Recently larger pipes up to a foot in diameter have been installed under water for transporting gas and oil, and conduits of similar sizes have been considered for electric power. The installation of the larger lines in marine waters poses new problems to the geologist and oceanographer. Investigations of the environment have been made in connection with a proposed installation of an 11-inch overall diameter 230-KV power line across Puget Sound where depths approach 700 feet. Particular attention was given to the steepness of the slopes and possible bottom irregularities. Physical and chemical tests were made on the sediments as a basis for estimating bearing capacity, chemical activity, and movements of the sediments, and for learning about the biological substratum. Biological studies were directed toward estimating the possible extent of fouling and attack on the protective pipe coating. The characteristics and movements of the overlying waters were investigated, as the sea water could affect the pipe directly by its motion and corrosive action, and indirectly through its contact with the sediments and living organisms.

IMPROVEMENT IN SEISMOGRAMS BY COMPUTATIONAL PROCEDURES

Roland F. Beers and Clifford F. Casey
P. O. Box 1015, Troy, N. Y.

Recent developments in the theory of information have led to computational procedures which sometimes enhance the signal-to-noise ratio of recorded data. A curve follower is used to transfer seismograms to magnetic tape. In this form various computational procedures can be performed to study their effect on earthquake records. Correlation procedures as well as other mathematical operations are employed to demonstrate some of the effects of these procedures.

EVIDENCE FOR WORLD-STRAIN READJUSTMENT FOLLOWING THE KAMCHATKA EARTHQUAKE OF 4 NOVEMBER 1952

Hugo Benioff
California Institute of Technology, Seismological Laboratory, Pasadena, Calif.

This investigation is a continuation of the author's study (1953) of the seismogram of the Kamchatka earthquake written by the three-minute galvanometer period N.-S. electromagnetic strain seismograph. In that paper waves up to 7.9 minutes period were described. In addition to these waves, the mean position of the recording line appeared to be disturbed during the time interval in which they were arriving. Since the recording line was undisturbed on the day preceding

the earthquake as well as on the following day, it seemed desirable to investigate the possibility that this disturbance might be due to an ultra long-period strain associated with the earthquake. Accordingly, a copy of the seismogram was drafted by R. Gilman in which the ratio of amplitude to time was increased 22 times which, in effect, reduced the recording rate by the same factor. This copy clearly exhibits a number of very long period waves or oscillations varying in period from 57 minutes to several hours. The very prominent 57-minute oscillation probably represents a free vibration of the earth as a whole in a mode in which the earth takes the forms of a prolate and oblate spheroid alternately. One long-period pulse lasting more than 6 hours is interpreted as possibly representing a heavily damped readjustment over the whole earth of the crustal or mantle strain in response to the localized strain release which generated the earthquake.

FUSED QUARTZ EARTH STRAIN-METER

Hugo Benioff
California Institute of Technology, Seismological Laboratory, Pasadena, Calif.

A fused quartz earth strain-meter has been installed in an abandoned tunnel in Dalton Canyon. The fused quartz indicator tube is 25 meters long. Secular strains are measured with a filar microscope reading to 0.001 mm corresponding to an earth strain of 4×10^{-8}. Preliminary photographic recording of dynamic strains has been started using a double bowstring optical mirror device with a magnification of 12,000. The resulting recording has a sensitivity of 1 mm per 4×10^{-9} strain. With this magnification the earth tides are clearly recorded. The present recording drum speed is 1 cm per hour. It is planned to include two additional recorders operating at a faster and a slower rate. These will be actuated by a capacity transducer operating with a constant-frequency carrier oscillator as described in previous reports.

LONG-PERIOD VERTICAL-COMPONENT SEISMOMETER

Hugo Benioff
California Institute of Technology, Seismological Laboratory, Pasadena, Calif.

A vertical-component seismometer for long-period waves is being developed jointly with L. Blainey. The instrument has a period of 10 seconds and is overdamped electromagnetically approximately 10 times the critical value. Output is derived from a capacity transducer of the type described in a previous report except that the oscillator operates at 100 kc and is driven by transistors. The pendulum has two alloy springs. One is mounted vertically and supports the pendulum mass. The other is mounted horizontally and provides a negative restoring force which increases the period from 1.5 seconds with vertical spring only to 10 seconds with both springs acting. The transducer output is proportional to the pendulum displacement rather than the velocity as in electromagnetic instruments, and it is expected therefore to provide a better response for waves longer than 1–2 minutes.

QUARTZ CRYSTAL CLOCK

Hugo Benioff
California Institute of Technology, Seismological Laboratory, Pasadena, Calif.

A new form of quartz-crystal clock has been developed for use in place of Marine-type chronometers. The timing element is a Bliley 100 kc standard oscillator. This unit has a low-temperature coefficient crystal maintained in a constant temperature oven. The counter is made up of a series of Wang magnetic flip-flops known as Perma-Memory Multiple Scalers. With the 100 kc input to the counter, the output frequency is 1 per minute. Since the output from the counter consists of impulses of approximately 10 microseconds' duration, a pulse-lengthening circuit has been provided for increasing the pulse duration to approximately 1½ seconds for operation of the relay which delivers current to the seismograph time markers. In addition, the output impulse is connected to an IBM minute-impulse clock for providing a visual indication of the time. The impulse clock is

fitted with an hour cam for supplying contacts for the hour marks on the seismograms. The frequency stability of this crystal clock is approximately within $\frac{1}{10}$ second per week. The original cost is less than that of a good Marine chronometer, and it is anticipated that the maintenance cost will also be less. Using a radio receiver tuned to WWV, the rate of this clock can be readily adjusted to within one part in 10^7 by observing beats between the 100th harmonic of the oscillator and the fundamental of WWV.

STRAIN CHARACTERISTICS OF THE KERN COUNTY EARTHQUAKE SEQUENCE 1952–1953

Hugo Benioff
California Institute of Technology, Seismological Laboratory, Pasadena, Calif.

The elastic strain-rebound characteristics of the aftershock sequence of the Kern County earthquake of July 21, 1952, indicate that shocks originating southeast of the fault form a compressional release series of the type $a + b \log t$, whereas those on the northwest side form a shear series of the type $A + B(1 - \exp \alpha t^{\frac{1}{2}})$. Moreover, the onset of the latter series was delayed for 37 hours, similar to the delay of the shear series in the 1933 Long Beach earthquake. In the original theory of aftershock generation it was assumed that aftershocks occur only along the principal fault. Observations in the Kern County sequence indicate that aftershocks occur on auxiliary faults within the original strain zone at least as much as on the principal break. Assuming that the original strain-zone surface area is defined by the aftershock-epicenter distribution and that faulting extended downward to the Mohorovicic discontinuity, the volume of strained rock from which the energy of the principal shock was derived is 7.3×10^{19} cm³. The average strain-energy density was 1.9×10^8 ergs/cm³, and the average elastic strain was 9×10^{-5}. On this basis, the relative slip of the two fault surfaces was 3.2 meters.

METAMORPHISM IN THE SNOWKING AREA, NORTHERN CASCADES, WASHINGTON

Bruce Bryant
Department of Geology, University of Washington, Seattle, Wash.

The Snowking area consists of metamorphosed and metasomatized geosynclinal sediments and volcanics. Shales, commonly calcareous or dolomitic, graywackes, intermediate and basic volcanics, and gradational mixtures predominate. Pure argillites, carbonate rocks, and quartzites are rare.

Synkinematic isochemical metamorphism has altered shales to garnet-biotite schists, zoisite, clinozoisite, or epidote-bearing if calcareous; dolomitic shales, partly with tuffaceous or graywacke components, to hornblende-biotite schists and para-amphibolites, usually with zoisite or epidote; more strongly dolomitic-calcareous layers to lime silicate bands, partly containing diopside with contemporaneous epidote; volcanics to plagioclase-rich ortho-amphibolites, many with epidote or clinozoisite. Nearly all these rocks contain sodic andesine. With regard to the metamorphic grade, the occurrence of contemporaneous diopside and epidote, as well as the association epidote-zoisite and andesine, are critical, indicating the upper limit of the epidote-amphibolite facies or the warmer part of the kyanite zone. (*Cf.* P. Misch, unpublished manuscript.)

To the north the schists and amphibolites grade into metasomatic, gneissose, and directionless granitic rocks ranging in composition from quartz diorite to granite. Soda metasomatism predominates except locally where introduction of late potash, accompanied sometimes by considerable silica, has been strong. The feldspars grew under static conditions. Trondjhemitic and granodioritic compositions predominate.

The metasomatic rocks display granoblastic textures, obvious replacement features, and feldspar porphyroblasts. Locally increased freedom of crystallization has permitted the formation of an igneous-appearing texture, suggesting local mobilization, which is confirmed by intrusive field relations. In the mobilized rocks, large, often euhedral crystals (mainly plagioclase) have been the last to form and are porphyroblasts rather than phenocrysts.

ATTITUDE AND NATURE OF MOVEMENT ON WHITE WOLF FAULT DURING ARVIN-TEHACHAPI EARTHQUAKE OF JULY 21, 1952

John P. Buwalda and Pierre St. Amand
California Institute of Technology, Pasadena, Calif.; Naval Ordnance Test Station, Inyokern, Calif.

Several types of evidence indicate that the White Wolf fault is not a dominantly strike-slip vertical fault like the San Andreas but a reverse or thrust fault dipping 45°–60° SE.

Evidence of different kinds bearing on magnitude and direction of fault movement is not very concordant. Retriangulation and precise releveling by the U. S. Coast and Geodetic Survey indicate that the northeast part of the upper block southeast of the White Wolf fault moved several feet north and rose 1–2 feet but with upbowing with the largest upward movement several miles southeast of the fault; horizontal displacement of the opposite side of the fault is not known, but there was very little vertical change. Along the middle part of the fault, points on the upper block moved northwesterly 1–2 feet and rose 2 feet or more; on the lower block the one triangulation point moved westward about 1.75 feet and dropped about the same amount, with the vertical displacement concentrated near the fault. On the Bakersfield-Los Angeles highway, near the southwest end of the fault, little is known regarding horizontal movement, but the southeast block rose 2 feet or more, and the northwest side bowed down about the same amount, the whole vertical displacement being a broad warp. Bakersfield did not change elevation. Hence the movements apparently varied greatly along the fault and were quite complex.

SIERRAN ROOT

Perry Byerly and Burl Tuller
Dept. of Geol. Sciences, Univ. of California, Berkeley, Calif.

Seismograms from the Reno station show that P_n is delayed in its arrival at Reno for earthquakes with central and northern California epicenters. The delay is 2.5 to 3 seconds. This delay indicates that the root of the Sierra Nevada extends to the northern end of the range. Previously a delay to the Owens Valley stations from shocks similarly located showed the southern Sierra Nevada to have a root. The delays for these southern stations were a second or two greater than for Reno. A bit of isostatic balancing of the Sierran mass against Raitt's Pacific and our standard California column shows that the mountain root and much of the mass above it must be "basalt"—a wholly granitic mass could not provide a root for mountains as low as the northern Sierra Nevada.

TP WAVE

Perry Byerly and Burl Tuller
Dept. of Geol. Sciences, Univ. of California, Berkeley, Calif.

Many West Indian earthquakes are recorded at stations near the Atlantic coast with a conspicuous arrival 12 to 35 seconds after *P*. This wave has the frequency of a *T* wave, period less than 0.9 second with 0.7 most common. It occurs usually in earthquakes which also record *T* waves later. It appears that this wave has travelled 20 to 60 km in water near its source. For the earthquakes investigated, there is little trouble in picking such a possible path on hydrographic charts if one is willing to move the Coast Survey or Jesuit Seismological Association epicenters a couple of tenths of a degree.

EAGLE GORGE DAM SITE, WASHINGTON

Allen S. Cary
Corps of Engineers, Seattle, Wash.

The Eagle Gorge Dam Site is being studied by the Seattle District Corps of Engineers for flood control on the Green River, one of the principal streams draining the western slopes of the Cascade Mountains in the State of Washington.

Topographic and physiographic peculiarities of the site, coupled with (1) the present use of the river as a water supply for the City of Tacoma and (2) the very wet climate, impose strict limitations on the design, in fact practically dictate an earth and rock fill dam with a pervious core and steep rock shells.

The pervious core must be continuous with and grade into an impervious blanket over the exposure of a pervious morainal embankment in an interglacial channel which skirts the right abutment.

Because of the very limited area and height of rock making up the right abutment a concrete gravity, buttress, or arch-type dam cannot be built economically.

GENESIS OF PERLITE

Charles W. Chesterman
California State Division of Mines, Ferry Building, San Francisco, Calif.

Detailed field investigations of many perlite bodies in California indicate that the perlite was formed from obsidian through the introduction of water vapor and the consequential development of perlitic structure. The occurrence of small rounded fragments of obsidian in perlite and their relations to the perlite suggest the following process: (1) emplacement of the obsidian as domes, sills, and dikes, (2) brecciation of the obsidian during or following emplacement, (3) introduction of water into the obsidian, the extent of the alteration (perlitization) depending upon the access of the water vapor to the obsidian, and (4) late-stage alteration of the perlite in part to clay, and intrusion of rhyolite into the perlite.

The alteration of the obsidian to perlite was affected by water vapor which could have been derived in part from the country rock or from the crystallizing rhyolite. The pumiceous character of some perlites indicates the lack of sufficient pressure to prevent vesiculation. The Staats perlite deposit in the northern part of the Coso Range, Inyo County, California, illustrates well the above process.

IMPORTANCE OF HIGHER MODES OF VIBRATION IN THE EARTHQUAKE RESPONSE OF A TALL BUILDING

Ray W. Clough
Division of Civil Engineering, University of California, Berkeley, Calif.

Some workers have suggested that only the first mode of vibration is of significance in determining the response of a building to an earthquake motion. This paper investigates the validity of this proposition in a particular case.

Using high-speed automatic computing machines, the response of a 15-story building in its first three modes of vibration to the El Centro earthquake of May 1940 was computed, assuming several different degrees of damping for each mode. From these response curves, the maximum values of displacement, inertia force, shear, and bending moment were obtained at various levels in the structure. A comparison of these data indicates the relative importance of the first three modes of vibration in the total response of the building. The corresponding values of force recommended by various building-design codes have also been included in the comparisons.

STRUCTURAL SYSTEMS IN PRECAST TYPE I WAREHOUSE DESIGN

F. Thomas Collins
921 West Las Tunas Drive, San Gabriel, Calif.

The major systems are discussed with regard to resistance to lateral forces. Slides showing damage in Bakersfield lead to modification of previous ideas of earthquake resistant design.

PATTERN OF STRUCTURE AND COMPOSITION IN A SMALL SIERRA NEVADA BATHOLITH

Robert R. Compton
Stanford University, Calif.

Bald Rock batholith, one of a chain of small plutons of the northwest Sierra Nevada, shows an interesting relation between its internal structure and its compositional units. Emplaced near the close of, or after, the Nevadan orogeny, this batholith forcefully and concordantly intruded the vertical foliation of a regional greenschist terrane and then extended its east and west borders by some process of crosscutting. Concentric outliers and near-contact injection dikes suggest stoping, but inclusions in the batholith are comparatively scarce. Compositional zoning from a trondhjemite core to a tonalite rim may mean that basic, stoped wall rock has been somehow imbibed by trondhjemite magma. The planar flow structures, everywhere nearly vertical, are critical in this regard, because they are not everywhere concentric to the contact and they locally cut across the compositional zones. Petrologic evidence supports a hypothesis of assimilation, but theoretical difficulties are recognized. The pattern of structure and composition are interpreted in light of other studies of granitic bodies. It appears that in Bald Rock batholith the flow structures are post-intrusive rather than pene-intrusive in origin. It is concluded that this intrusion may well have been hotter and more mobile than most granitic intrusions are supposed to have been.

RECENT MUDFLOW OF EXCEPTIONAL DIMENSIONS FROM MT. RAINIER, WASHINGTON

D. R. Crandell and H. H. Waldron
U. S. Geological Survey, Denver, Colo.; U. S. Geological Survey, Seattle, Wash.

A Recent mudflow from Mt. Rainier is estimated to have originally covered an area in excess of 65 square miles and to have had a total volume of one billion cubic yards or more. The mudflow deposit extends from the northeast side of Mt. Rainier 45 miles down the White River valley to the west front of the Cascade Range. Here it spreads out on the Puget Sound lowland in the form of a lobe 20 miles long by 3 to 10 miles wide. Margins of the lobe are digitate, with narrow fingers extending as much as 4 miles beyond the main body. The upper surface, while appearing remarkably flat, has a slope of about 25 feet per mile.

The mudflow deposit ranges in thickness from a few feet to 350 feet and typically is unsorted, unstratified, and highly plastic. It contains abundant andesite lava fragments from Mt. Rainier.

The deposit originally was named the Osceola till by Bailey Willis in 1898; he regarded it as the till of a Cascade piedmont glacier. The stratigraphic relations and the distribution of the deposit, however, suggest that it originated as a volcanic mudflow from Mt. Rainier.

In the Puget Sound lowland the mudflow overlies a soil profile developed on Vashon drift (late Wisconsin?). Assuming that this soil formed during the "Climatic Optimum," the mudflow is less than 5000 years old.

MECHANISM OF SURFACE-WAVE GENERATION

C. Hewitt Dix
Div. of Geol. Sciences, California Institute of Technology, Pasadena, Calif.

The writer has given (Seismic prospecting for oil, p. 366–369) what may be an acceptable rough physical picture of the process by which surface waves may be generated by a buried explosive source. This investigation shows how this rough picture may be made precise. The method is Cagniard's, as suggested in the above reference. The procedure is to calculate a numerical example due to an impulsive step-pressure source in a buried spherical cavity. Cagniard's potentials A and B can be very simply computed along a line through the source perpendicular to the free surface. These are each zero until its corresponding pulse can reach the field point. After this B remains zero, but A increases steadily and diverges with increasing time like t^2. As the vertical displacement is partly calculated

from $\delta A/\delta t$ this contribution also diverges with t. But the contribution from B subtracts just what is necessary to make the vertical displacement return to zero as t approaches infinity. This divergence is due to the continual exchange of type taking place at the free surface coupled with backward and lateral transmission of the secondary pulses. This is a long nonoscillatory change that builds up from the beginning of P until the beginning of S. This slowly built-up displacement is a long wave which reaches its maximum after the earliest S wave has passed the station. But it begins to develop immediately after the P wave. Graphs illustrate the process.

PERFORMANCE OF RESONANT SEISMOMETERS

W. L. Donn, Maurice Ewing, and Frank Press
Lamont Geological Observatory (Columbia University), Palisades, N. Y.

A group of resonant vertical seismometers, each tuned to cover a part of the spectrum of microseism frequencies, has been operated for about a year. These instruments

(a) clearly distinguish between simultaneous microseisms from two separate sources,

(b) show an improved signal-to-noise ratio for microseisms from a single storm, permitting earlier detection of storm onsets,

(c) show clearly the increase in period of frontal microseisms as storms move seaward from the east coast of North America, and

(d) record only the envelope of the oscillations, which greatly facilitates measurement of intensity as a function of time.

EARTHQUAKE STRAIN MEASUREMENTS IN A REINFORCED CONCRETE BUILDING

C. Martin Duke and Robert A. Brisbane
University of California, Los Angeles, Calif.

Records of strain in concrete and strain in steel in a four-story reinforced concrete building in Los Angeles have been obtained during two minor earthquakes. Simultaneous records were obtained of ground acceleration at the base of the building. Instrumentation included an oscillograph to record strains as a function of time, a strong-motion accellerograph, Carlson and SR-4 strain transducers, and an automatic starting mechanism. Strain calibration was by static loading of the building.

The paper describes the building and the instrumentation and presents the measured results. Dynamic computations have been attempted, using a mechanical differential analyzer, to relate measured ground accelerations to measured strains, but the comparison has been poor due, it is thought, to insensitive measurement of the accelerations.

Maximum concrete stress in the building in the Arvin earthquake of January 12, 1954, was of the order of 50 pounds per square inch.

The instrumentation is maintained in operation for the recording of strains in future earthquakes.

NEW LAND MAMMAL AND MARINE MEGAFOSSIL ASSOCIATIONS IN THE NEOGENE OF CALIFORNIA

J. Wyatt Durham and Donald E. Savage
Museum of Paleontology, University of California, Berkeley, Calif.

Recently two significant associations of continental vertebrates and marine invertebrates have been discovered. The more important site is at Comanche Point, 18 miles southeast of Bakersfield, California. Here a *Hipparion*, comparable to *H. mohavense* Merriam, and other vertebrate fossils were found below the beds with marine mollusks in the Santa Margarita formation of Hoots (1930). The vertebrates would indicate an approximate mid-Clarendonian (early Pliocene) age in the continental sequence. The overlying invertebrate fauna includes *Ostrea titan* Conrad, *Lyropecten crassicardo* (Conrad), and others, signifying an age not younger than the Santa Margarita "stage" (latest Miocene) of the marine sequence. *Hipparion* cf. *forcei* Richey and other mammals of late Clarendonian age are found in strata immediately overlying the marine "Santa Margarita".

The second locality is on the Cammatta ranch, about 25 miles southeast of Paso Robles, California. Here a *Hipparion* of Clarendonian type and other poorly preserved vertebrates, derived either from a bed at the base of the marine Santa Margarita or from subjacent locally nonmarine sediments were found. The fauna of the overlying marine Santa Margarita includes *Ostrea tilan* Conrad and *Lyropecten crassicardo* (Conrad). Still higher in the Santa Margarita *Lyropecten estrellanus* (Conrad), *Astrodapsis salinasensis* Richards, and an *Astrodapsis* of the *whitneyi* type occur. These marine fossils indicate a Santa Margarita "stage" age.

These two occurrences are similar to that in the Mint Canyon area and further corroborate that part of the Clarendonian is correlative with the Santa Margarita "stage" or equivalent marine units.

BETA-CEROLITE

N. Efremov
1061 Intervale Ave., New York, N. Y.

I. Ginsburg and I. Rukavishnikova (Beta-cerolite, Mem. All-Russian Min. Soc. LXXIX, no. 1, 1950) described a new mineral, beta-cerolite ($3MgO \cdot 3SiO_2 \cdot 4H_2O$) which they consider to be a polymorphous variety of cerolite. According to the authors their investigations elucidated two varieties of cerolite which are chemically identical, but whose optical, thermal, and x-ray data differ. Therefore the authors propose to call cerolite "alpha-cerolite" and the new mineral described by them "beta-cerolite".

A comparison of the data of our previous investigations of minerals of sepiolite group with the data cited by Ginsburg and Rukavishnikova suggests that "beta-cerolite" of the authors is a typical sepiolite. It strictly corresponds to the chemical composition of the first member of the sepiolite group, $3MgO \cdot 3SiO_2 \cdot 4.5H_2O$, according to classification proposed by the author (1953). The optical properties of "beta-cerolite" are the same as those of sepiolite. Comparing the x-ray data for sepiolite from Cabanas (*cf.* Alekseeva and Godlevsky) and those for "beta-cerolite," one can see that the main lines most characteristic for sepiolite appear for "beta-cerolite" almost with the same intensity. Therefore the mineral name "beta-cerolite" is not justified.

YOUGORITE, A LISTWÄNITE ROCK RICH IN FLUORITE

N. Efremov
1061 Intervale Ave., New York, N. Y.

Listwänites belong to metamorphic rocks formed by hydrothermal metamorphism. In many cases they contain significant quantities of different metals and minerals of economic importance (gold, fluorite, apatite, etc.). Listwänites may form as a result of the influence of carbonic hydrothermal solutions on the ultrabasic, basic, or medium igneous rocks, or on the metamorphic or sedimentary rocks corresponding to them in composition. Among different types of listwänites those formed from limestones are of special interest. Many of these listwänites are enriched in apatite (apatite type) or in fluorite (fluorite type). Yougorite is a representative of the latter and a variety of metasomatized limestone. It is greenish purple or greenish gray, massive or schistose rock consisting of fine-grained aggregate of quartz, fluorite, and sericite with a small amount of calcite, dolomite, and pyrite.

Yougorite is fairly abundant in the Yougorian Peninsula (Amderma district in the Arctic part of the USSR) and is of economic importance as fluorite ore. Most of the Amderma fluorite ore is concentrated in yougorite bodies varying from irregular nests and flats to beds. The size of these bodies varies from a few centimeters up to 7–8 meters. The origin of the deposit is typically mesothermal.

EARTHQUAKE RESISTANCE OF ADDITION TO HAROLD'S CLUB IN RENO, NEVADA

H. M. Engle
Civil and Structural Engineer, 110 Sutter St., San Francisco, Calif.

This nine-story addition, 135 feet high, and only 26 feet wide, is braced to resist earthquake forces. using lateral forces of 10 per cent of the dead load, plus 25 per cent of the live load. Four stories of the

existing club building are carried on the north wall of the addition. Existing floors are carried on sliding joints to prevent pounding between addition and the old building under wind and earthquake loads. Stiffness, rigidity, and control of lateral deflections were major considerations in the design. The cost increase due to provision for lateral forces at 10 per cent was not over 2 per cent.

SHORT-PERIOD SURFACE WAVES AT CONTINENTAL MARGINS

Maurice Ewing, Frank Press, Jack Oliver, D. H. Shurbet, and William L. Donn
Lamont Geological Observatory (Columbia University), Palisades, N. Y.

Many lines of investigation suggest that the continental margin is a very effective barrier for short-period surface waves ($T < 15$ sec $\pm$). It is postulated that

(a) short-period surface waves of Love or Rayleigh type are effective scattered and transformed into the opposite type at continental borders and islands;

(b) short-period Rayleigh waves are absent over typical oceanic paths. They probably are the effect of decoupling introduced by the velocity gradient in the water. All short-period surface waves over these paths are Love waves.

(c) The great duration and unexpected components of motion in *Lg*, *Rg*, and short-period ocean surface waves are due to scattering and transformation.

(d) Storm microseisms are effectively generated only when an atmospheric energy source covers an area of rapid gradient in crustal thickness.

PARTIAL CONTEMPORANEITY OF THE KEECHELUS FORMATION AND THE PUGET GROUP IN SOUTHERN WASHINGTON

Richard V. Fisher
Geology Department, University of Washington, Seattle, Wash.

The Keechelus formation, covering hundreds of square miles in the southern Washington Cascades, is a thick sequence of andesitic volcanic breccias, tuffs, flows, and interbedded continental sediments. It is usually gently folded and is intruded by small dioritic stocks and diabasic dikes. Its age has been variously regarded as Miocene and/or Oligocene. On the basis of a single oreodont, it is now thought to be mainly Oligocene.

Immediately south of Mt. Rainier, the lower part of the Keechelus is interbedded with the upper part of the probable upper Eocene Puget Group. Keechelus breccias grade into graywackes which in turn interfinger with Puget sandstones. The Keechelus, therefore, appears to belong in part to the upper Eocene.

Supporting evidence is from two areas. One is near Chehalis where Snavely described a unit similar to the Keechelus (Northcraft formation), which he determined to be upper middle Eocene by its position between two marine formations. The Northcraft is probably a westwardly extending tongue of the Keechelus. The other area is near Seattle where Warren described 7000 feet of probable upper Eocene volcanics underlying Puget sediments. These pre-Puget volcanics are lithologically similar to overlying volcanics which he called Keechelus.

In the southern Washington Cascade region, on the basis of marine fossils, Keechelus volcanism appears to have begun during Eocene time. Near the close of the Eocene, volcanism began on a large scale and, on the basis of the oreodont, presumably continued through most of the Oligocene.

STRATIGRAPHY AND PALEONTOLOGY OF THE TYPE BLAKELEY FORMATION OF WASHINGTON

Charles V. Fulmer
Explor. Standard Oil Co., Seattle, Wash.

The type section of the Blakeley formation is exposed in the sea cliffs along the entrance to Bremerton Inlet and along the southeastern shore line of Bainbridge Island.

Charles E. Weaver (1912) applied the name Blakeley formation to the Bainbridge Island section consisting of approximately 8000 feet of conglomerates, sandstones, siltstones, and shales. Later, Weaver included in the Blakeley formation a basal conglomeratic unit exposed at Orchard Point.

The strata constituting the type Blakeley formation, as recognized by Weaver, can be grouped into three lithogenetic units. The lowermost 845 feet consists of well-bedded, hard, marine, gray sandstones, and massive conglomerates, the Orchard Point member. The middle unit consists of approximately 4000 feet of marine, hard, massive, gray-tan siltstone interbedded with thin, hard, fine-grained sandstone; soft, limonitic-stained sandstone largely covered by beach gravels; and massive, dark-gray, silty shale. This lithologic unit is the Restoration Point member and contains the typical Blakeley molluscan faunule.

The upper lithologic unit consists of approximately 4650 feet of massive, nonmarine conglomerates interbedded with thin, gray sandstones, and soft carbonaceous siltstones.

The writer recommends that the Blakeley formation be restricted to the Orchard Point and Restoration Point members, and that the overlying nonmarine conglomeratic interval be referred to a new formation.

The restricted Blakeley formation, based on the foraminiferal assemblages contained, is best correlated with the Zemorrian stage of California.

STRATIGRAPHY AND PALEONTOLOGY OF THE TYPICAL MARKLEY AND NORTONVILLE FORMATIONS OF CENTRAL CALIFORNIA

Charles V. Fulmer
Explor. Standard Oil Co., Seattle, Wash.

The type sections of the Markley and Nortonville formations are located on the northeastern flank of Mt. Diablo, approximately 35 miles east of San Francisco, California, and about 12 miles southwest of the junction of the Sacramento and San Joaquin rivers.

At the type locality the overlying Markley formation consists of two argillaceous, feldspathic, well-sorted, marine sandstone members with an intervening light-gray, slabby, marine, organic, shale member. The Nortonville formation, at the type section, is also a tripartite lithologic unit composed of two chocolate-brown marine, silty clay shales with an intervening argillaceous, feldspathic sandstone lentil. The upturned edges of these two formations are exposed in a lenticular, elongate outcrop striking northwest with regional dip to the northeast. The superjacent and subjacent Tertiary strata are involved in a complex monoclinal structure flanking Mt. Diablo on the north and east.

The Nortonville formation contains three distinctive foraminiferal associations which can be referred to Laiming's Eocene zones, the B-1 or B-2, and the A-2. These faunules can also be correlated in part with Mallory's newly proposed Eocene Ulatisian and Narizian stages.

The Sidney Flat shale member of the Markley formation contains a distinctive foraminiferal association nearly identical in composition with Laiming's typical A-1 zone assemblage and correlates in part with Mallory's Fresnian stage.

The stratigraphic occurrence and ecologic interpretation of the foraminiferal assemblages will be discussed.

BANDED CHROMITES—A NEW THEORY OF ORIGIN

Bert E. Griffin
University of Washington, Seattle, Wash.

While it has long been thought possible to form bands of chromite by crystallization differentiation from a gabbroic melt, there has been some skepticism about the concept. However, the occurrence of banded chromites at the bottom of noritic layers has convinced many people that gravitative settling took place. It is more difficult to explain the absence of these layers in the underlying dunites, particu-

larly when minute crystals of chromite are observed speckled throughout the olivine masses. Under the microscope, it appears that there has been no refusion of the chromite crystals, as would be expected if the material had settled gravitatively. It appears that the chromite crystallized simultaneously with the silicates.

The mineralogy of chromites shows a remarkable conformity to the ternary diagram of the system Mg_2SiO_4-$CaAl_2Si_2O_8$-SiO_2. Wherever the banded chromites are found, there, also, are the localized concentrations of plagioclase and clino-pyroxene. Examination of chromites from the Bushveld, Skaergaard, Stillwater, and Table Mountain sequences shows remarkable uniformity with respect to composition. It is proposed that the banded chromites are a product of reaction in a favorable chemical environment rather than a gravitative accumulation.

X-ray examination shows considerable variation in the crystal lattices of the chromites and indicates a wide compositional range. Examination, after heating to 600°C, showed that some chromites separated into two phases and were not primary; in these cases, a hydrothermal origin seems most probable.

SLIP DIRECTION IN EARTHQUAKES CALCULATED FROM OBSERVED RATIOS *SH/SV*

B. Gutenberg
Seismological Laboratory, 220 N. San Rafael Ave., Pasadena, Calif.

The polarization angle ϵ of transverse waves ($\tan\epsilon = SH/SV$) can be calculated from *NS* and *EW* components of *S* recorded at stations with two horizontal seismographs having about the same characteristics. If $r = EW/NS$, and u = ratio of ground amplitude to incident amplitude of the horizontal component of *SV* as function of angle of incidence i,

$$\tan\epsilon = u(r\cot\gamma - 1)/2(r + \cot\gamma)$$

where γ = azimuth at the station toward the epicenter. On the basis of equations developed by J. M. Nordquist, ϵ can be calculated from

$$\cot\epsilon = (\cos i \cos\alpha - \cot\beta \sin i)/\sin\alpha$$

where i = angle of incidence of the ray, α = difference between azimuth of the station at the epicenter and the strike of the fault, β = angle of incidence of the slip. Since $\epsilon = 0$, if $\alpha = 0$, the azimuth of the slip coincides with the azimuth in which *SH* is 0, or $r = \tan\gamma$. The method was successfully applied to records of the main Kern County earthquake, July 21, 1952. Values of ϵ plotted as function of α indicate that the direction of slip was approximately toward the north in the upper (southeastern) block relative to the lower. This result supplements information gained from the distribution of compressions and dilatations in *P*.

RESEARCH INTO THE NATURAL FREQUENCY OF SOILS

R. G. Hennes
University of Washington, Department of Civil Engineering, Seattle, Wash.

The development of resonances at building sites is of interest to the civil engineer wherever there is hazard of earthquakes or heavy machinery vibration. There is no common understanding within the engineering profession of the relative extents to which natural frequency of foundation soils is dependent upon the properties of the constituent soil particles or upon the stratification and boundary condition of the deposit itself. The present paper describes the dynamic testing *in situ* of five electrical substation foundations during 1950, and the subsequent attempt in 1951 to explore, by laboratory tests, the concept that the natural frequency of uniform sands could be expressed as a function of grain size and shape. The results of both investigations were instructive but not conclusive.

MID-ORDOVICIAN EROSION IN UTAH

Lehi F. Hintze
Oregon State College, Corvallis, Ore.

Restored isopach maps of the Ordovician of Utah indicate a positive element which was subject to erosion during mid-Ordovician time, and which extended westward from the Provo vicinity to Gold Hill near the Utah-Nevada State line. This positive pattern contrasts markedly with that of the upper Paleozoic during which time the same area was deeply subsiding.

SEISMIC STUDY OF CRUSTAL STRUCTURE IN PENNSYLVANIA AND NEW YORK

Samuel Katz
Lamont Geological Observatory, Columbia University, Palisades, N. Y.

Blasts at two quarries in northern New York and central Pennsylvania have been recorded to a distance of 309 km. The data indicate an essentially homogeneous crust, with elastic wave velocities possibly increasing with depth. An average crustal thickness for the region is 34.4 km, with no indication of significant difference in thickness between the two areas. Observed compressional wave velocities for the crust are 6.39 and 6.31 km/sec for New York, and 6.04 km/sec for Pennsylvania. The corresponding shear wave velocities are 3.62 and 3.60 km/sec, and 3.61 km/sec. Average upper mantle velocities are 8.14 km/sec for P_n and 4.69 km/sec for S_n. The compressional wave velocity of anorthosite near Tahawus, New York, is 6.63 km/sec. No near-vertical reflections from the Mohorovicic discontinuity were observed.

GEOLOGIC CAUSES FOR FAILURE OF LONE PINE RESERVOIR, EAST-CENTRAL ARIZONA

George A. Kiersch
University of Arizona, Tucson, Ariz.

Failure of Lone Pine Reservoir to hold water must be attributed to a complete disregard for geologic conditions. This earthfill dam (95 feet high) was built in mid-1930's. Initially the reservoir was successful, but serious leakage developed during the second year, and the impoundment basin became useless; reportedly a full reservoir (15,000–20,000 A.F.) leaked out within 6 weeks. Hydrostatic pressure apparently flushed the pre-existing openings and established an interconnected ground-water system.

The dam site is situated in a steep-walled canyon. Abutments are jointed lava underlain by Kaibab(?) limestone (25 feet thick) in the channel; not exposed at the dam is a thick section of underlying Coconino sandstone which crops out in the upper half of the reservoir. Regionally, all formations dip gently northeastward into the Little Colorado River basin. The reservoir is near the crest of a subsidiary anticline (northeast flank).

Recently, geologic studies were undertaken to: (1) ascertain causes of the reservoir failure, and (2) determine the feasibility of sealing the openings. All rocks permit leakage—the jointed Tertiary lava with interbeds of ash; the fractured Permian Kaibab(?) limestone with interconnected openings and sinkholes; and the inherently porous Permian Coconino sandstone. Folding fractured the basement rocks further. The gentle northeast tilt provides natural leakage; influent flow migrates down dip, and springs issue in tributary canyons.

Sinkholes in the Kaibab(?) limestone provide the principal openings for leakage, recharging both the limestone and underlying Coconino sandstone. Sealing methods would be extremely expensive and uneconomical owing to size of openings and areal extent and configuration of reservoir floor. Hydrostatic pressure of a near-capacity reservoir would flush a weakly bonded seal and reopen leakage channels.

LAYERED GABBRO AND RELATED ROCKS IN NORTHERN NORWAY

Konrad B. Krauskopf
Stanford University, Calif.

Layered gabbro underlies several of the islands and parts of the mainland near Hammerfest. Thick layers of syenite and thin layers of anorthosite and pyroxenite are interbedded with the gabbro. Locally other material is interbedded, notably norite, troctolite, dunite, garnet-biotite gneiss, and small lenses of meta-limestone. In most places the layers are thin, uniform in thickness over long distances, and show no regularity in sequence from mafic to felsic types. Although hand specimens look like ordinary igneous gabbro, the layering and the variety of interbedded rocks suggest that the gabbro may in part be the result of extreme metamorphism of a dominantly volcanic sequence. Small masses of structureless gabbro, syenite, peridotite, hornblendite, and anorthosite show contact relations which suggest that they are intrusive into the layered series.

T PHASE AT PAPEETE, TAHITI

Mark Landisman and Maurice Ewing
Lamont Geological Observatory (Columbia University), Palisades, N. Y.

The short-period waves from distant earthquakes reported by Ravet (Proc. Sixth Pac. Sci. Cong., 1940, p. 127–130) from seismograms recorded on the Mainka pendulums at Papeete, Tahiti, are *T* phases.

HADROSAURS IN BAJA CALIFORNIA

Wann Langston, Jr. and Millis H. Oakes
Museum and Department of Paleontology, University of California, Berkeley, Calif.

Hadrosaurs (duck-bill dinosaurs) are among the most common Upper Cretaceous dinosaurs, but they are rarely found outside the United States and Canada. Only one occurrence has hitherto been recorded from Mexico, in the State of Sonora near the International Boundary.

Recently hadrosaur remains have been discovered on two occasions on the west coast of the State of Baja California, about 5 miles north of Punta San Ysidro. Two individuals about the size of *Kritosaurus* are represented by foot bones in the collections of the Museum of Paleontology at the University of California (no. 43251). The fossiliferous yellow "packsand" is exposed in discontinuous outcrops along beaches and sea cliffs and is rarely exposed inland. This sand was deposited unconformably on Middle Cretaceous rocks in numerous restricted embayments along the Late Cretaceous shore line which at this point was apparently in close proximity to the present one.

The echinoid genera *Trochalasoma* (*Plistophyma*), *Phyllobrissus*, and *Conulus* (or *Galerites*) along with the rudistid pelecypod *Coralliochama orcutti* occur in the same beds as the dinosaur and appear to restrict the age of the rocks to late Senonian or Maestrichtian. This age corresponds to that of the California occurrences of hadrosaurs in the Moreno formation.

TECTONIC INFLUENCE ON SEDIMENTATION IN CENTRAL UTAH

H. K. Lautenschlager
Standard Oil Co. of California, P. O. Box 646, Santa Maria, Calif.

During 1950 and 1951 a portion of the Pavant Range in central Utah was mapped. The most significant structural feature in the area here discussed is the Pavant thrust fault, which embodies the thrusting of Lower Paleozoic beds over Lower Mesozoic formations. As a result of related uplift and erosion and subsequent deposition, Upper Cretaceous and Lower Tertiary beds now rest on Cambrian and Ordovician formations. The absence of nearly all Jurassic and Cretaceous sediments indicates that the Pavant Range was near the eastern margin of a linear north-south orogenic belt that profoundly affected sedimentation in east-central Utah.

SILICOFLAGELLATES BROUGHT UP TO DATE

York T. Mandra
San Francisco State College, 1600 Holloway Ave., San Francisco, Calif.

The history of silicoflagellate investigations from Ehrenberg to Borgert in the nineteenth century and from Lemmermann to Hanna in the twentieth century indicates that many opportunities for original work are still available in this field of study.

The status of the "soft and hard part morphology" and the taxonomic classification of the silicoflagellates indicate that much biological work is needed in this area. Almost complete neglect on the part of previous workers of the detailed stratigraphic approach of these organisms points out another fertile field of study. Only when data from these fields are properly analyzed and organized will the confusion surrounding these creatures be dissipated.

QUATERNARY STRATIGRAPHY AND GEOMORPHOLOGY OF THE FORT ST. JOHN AREA, NORTHEASTERN BRITISH COLUMBIA

W. H. Mathews
Dept. of Geology, University of B. C., Vancouver, B. C.

Unconsolidated sediments in the Fort St. John area include a twice-repeated succession of gravels overlain by sands, silts, and clays, and these in turn by tills of eastern origin. Both successions are interpreted as (1) gravels laid down by Peace River during or at the close of interglacial (and preglacial?) intervals, (2) fine sediments laid down in lakes ponded in Peace River Valley by ice advancing from the east, and (3) till laid down after ice reached the Fort St. John area. The younger till (early Wisconsin?) is covered by sediments, chiefly clay, from a series of proglacial lakes, and by local postglacial deposits.

The topography of the uplands reflects the form of the stream-eroded Cretaceous bedrock, modified slightly by glacial erosion and by a thin mantle of till. The land form at the intermediate levels is determined largely by the deposition of sediments in proglacial lakes both preceding and following the last glaciation from the east. Since the draining of the proglacial lakes Peace River has cut a trench 700 feet deep below the lake floor and 150–250 feet below its interglacial channel.

Ice from the Cordilleran area reached to within 15 miles of Fort St. John, overriding areas from which the early Wisconsin(?) eastern ice had already withdrawn, and depositing sediment in the last of the lakes in this locality dammed by the eastern ice.

BURIED SOIL ZONES IN THE PALOUSE LOESS, EASTERN WASHINGTON

John C. Mickelson
Dept. of Geology, State College of Washington, Pullman, Wash.

The Palouse loess is dominantly a silt with lesser amounts of fine sand and clay-size particles. In most instances it shows little or no bedding or lamination although locally it has the characteristic bedding and sorting of silts, sands, and gravels deposited in standing and/or moving waters.

The Palouse loess is characterized by a near absence of fauna which makes it most difficult to assign a definite age to the deposit. Physical relationships indicate a Pleistocene age and probably late Pleistocene. Within the main body of the Palouse loess are two quite well-defined buried soil horizons. The upper buried soil horizon occurs 4 to 10 feet below the surface and conforms to the present topography, with a high percentage of pumicite above. Lower in the loess section is another well-defined buried soil profile that has wide distribution throughout the loess area of eastern Washington. The development of these soils and their subsequent burial make it possible to delimit and correlate members within the main body of the loess and may aid in finally assigning relative ages to the several units.

ENGINEERING ASPECTS OF EARTHQUAKE MOTION

A. L. Miller
University of Washington, Department of Civil Engineering, Seattle, Wash.

The fields of engineering and the natural sciences are intimately related. Their functions and viewpoints differ significantly. Mutual understanding is most essential to effective progress in both fields. The broad views of seismologists and the specific local problems of engineers should be correlated from time to time so that science can provide the factual basis for the solution of engineering problems of earthquake safety. To this end, the particular needs for information on the subject of strong motion measurements and interpretation are discussed from the engineering viewpoint together with suggestions for the proper use of present data.

CATACLYSMIC FLOOD WAVES IN LITUYA BAY, ALASKA

Don J. Miller
U. S. Geological Survey, Menlo Park, Calif.

Lituya Bay is a T-shaped fiord in the coastal lowland and foothills belt flanking the Fairweather Range, on the northeast shore of the Gulf of Alaska. The main trunk of the bay is 7 miles long and 1–2 miles wide. Two zones of even-age trees bordering the shore record cataclysmic flood waves originating at the head of the bay. Each zone of trees is bordered by a sharp trim line that marks the upper limit of flood-wave destruction. The younger and lower trim line begins at an altitude of more than 400 feet at the head of one arm of the bay, intersecting the present shore line 1½ miles inside the entrance. The older and higher trim line attains a maximum altitude of 395 feet 2 miles from the head of the bay.

The younger flood wave occurred in the fall of 1936, according to the eyewitness account of one man, now dead. The older flood wave occurred late in 1853 or early 1854, according to tree-ring studies. Sudden release of an ice-dammed lake, ice fall, or movement of glaciers that discharge into the head of the bay seem unlikely as causes of the flood waves. Displacement along a known active fault at the head of the bay as a direct or indirect cause of the flood waves is suggested by their apparent high velocity and great height at the head of the bay, but evidence that they were accompanied or immediately preceded by earthquake shocks is lacking in the eyewitness account and in earthquake records.

RATE OF MOVEMENT OF ICE IN THE UPPER PART OF THE YAKATAGA GLACIER, ALASKA

Don J. Miller
U. S. Geological Survey, Menlo Park, Calif.

The Yakataga glacier occupies a steep-walled valley in the Robinson Mountains, on the north coast of the Gulf of Alaska. The main trunk of the glacier descends from 4000 feet altitude to 500 feet in 13 miles. A large rockfall on the head of the glacier prior to the midsummer of 1938 affords a measure of the rate of movement. The rockfall formed a superglacial moraine of distinctive shape, with unusually coarse debris. The position of the front of this feature in 1938, 1944, 1948, and 1952 is known from aerial photographs and ground observations. The front advanced approximately 370 feet per year between 1938 and 1944, 500 feet per year between 1944 and 1948, and 310 feet per year between 1948 and 1952.

LARGE OVERTHRUSTS NEAR CONNORS PASS IN THE SOUTHERN SCHELL CREEK RANGE, WHITE PINE COUNTY, EASTERN NEVADA*

Peter Misch and William H. Easton
Dept. of Geology, University of Washington, Seattle, Wash.; Dept. of Geology, University of Southern California, Los Angeles, Calif.

Reconnaissance mapping in 1951–1952 revealed three major eastward overthrusts which bound the following four structural units:

I. The substratum is Prospect Mountain quartzite with mostly dynamometamorphic remnants of Cambrian limestone. To the north, thick quartzites with some phyllites are probably Precambrian.

II. An inverted Devonian-Mississippian sequence overrides unit I. Structurally lowest is dynamometamorphic Joana limestone (Mississippian), locally sparsely fossiliferous. Pilot shale, altered to phyllite and slate, displays tectonic accumulation and reduction. It grades into shattered, fossiliferous Devonian limestone. Near Connors Pass these formations previously have been called Precambrian. Farther north, a normal Ordovician-Devonian sequence IIa intervenes between II and III, reducing II.

III. A normal Devonian through Permian sequence forms a thrust plate resting on inverted Devonian of unit II.

IV. A normal Devonian through Pennsylvanian sequence forms the highest plate. Imbrications of Joana limestone occur in III and IV.

The thrust between I and II outcrops in the eastern part of the range and descends southward to disappear under Spring Valley. Its probable eastern continuation occurs in the Snake Range. An analogous fault was found in the southern Cherry Creek Mountains to the northwest. The thrust between II and III also descends southward into Spring Valley. Unit IV forms a spectacular klippe above a nearly horizontal thrust. Having no root within the Schell Creek Range, it must have come from farther west.

North of Connors Pass, Cenozoic eastward tilting of this part of the range is demonstrated by thick Cretaceous? or Tertiary? conglomerates. Thirty miles farther north, Tertiary volcanics indicate westward tilting.

SCAWTITE AND BULTFONTEINITE FROM CRESTMORE, CALIFORNIA

Joseph Murdoch
University of California, Los Angeles, Calif.

Scawtite has been found in the contact zone at Crestmore, California, in narrow veins, both massive and in crystals. The crystals are thin tabular, usually clustered in subparallel groups, just like bundles of shingles. In the massive portion of some of the veins, fine sugary aggregates of bultfonteinite appear. In thin section these are seen to be made up of short, multiple-twinned prisms. Bultfonteinite also occurs similarly in some veins of massive afwillite, found in the same general locality.

Scawtite crystals are in general poor, but it has been possible to make approximate measurements on selected crystals and to confirm these by X-ray study. Forms present are as follows: (100) always present and dominant; (010) narrow, but usually present; (110), (120), and (130) narrow and poorly developed; (101) always present but fairly narrow. The mineral is monoclinic, with space group I 2/m, and the following cell dimensions:

$$a_0 = 10.217\ \text{Å} \qquad b_0 = 15.59\ \text{Å} \qquad c_0 = 6.715\ \text{Å}$$

$$a:b:c \qquad 0.64.34:1:0.4231 \qquad \beta = 100°29'$$

No separate crystals of bultfonteinite were found, but chemical and optical properties agree with

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descriptions of this mineral. X-ray powder photographs of the two minerals show the following spacings and intensities for the strongest lines:

Scawtite: 3.04 Å—10; 3.01 Å—5; 2.49 Å—5; 2.236 Å—5; 1.898 Å—6.
Bultfonteinite: 8.18 Å—7; 3.50 Å—5; 3.45 Å—5; 2.92 Å—10; 2.88 Å—10; 1.93 Å—7.

MODEL SEISMOLOGY IN TWO DIMENSIONS

Jack Oliver, Frank Press and Maurice Ewing
Lamont Geological Observatory (Columbia University), Palisades, N. Y.

The use of two-dimensional models greatly simplifies model studies of seismological problems. Results are given for diffraction of *P* waves at the core, Rayleigh waves in layered media, and the effect of layer thickness on the refracted waves of seismic prospecting.

Pn AND Sn VELOCITIES AT GREAT DISTANCES

Frank Press and Maurice Ewing
Lamont Geological Observatory (Columbia University), Palisades, N. Y.

One would expect that *Pn* and *Sn* waves could propagate over great distances by numerous multiple reflections at near-grazing incidence from the underside of the Mohorovicic discontinuity, in direct analogy with the whispering gallery effect discussed by Rayleigh. Phases showing the appropriate velocities have been found on the new Columbia University long-period instruments at epicentral distances up to 125°.

SOME RESULTS OF SEISMIC STUDIES ON *CAPRICORN* EXPEDITION

Russell W. Raitt
Scripps Institution of Oceanography, University of California, La Jolla, Calif.

On the University of California CAPRICORN Expedition of 1952–1953, two Scripps Institution of Oceanography vessels, R/V HORIZON and R/V SPENCER F. BAIRD, went from San Diego to the Marshall Islands, returning via the Fiji, Tonga, Samoa, Cook, Society, Tuamotu, and Marquesas islands. In the southwestern and southeastern parts, the route entered regions where various evidence had suggested that the sea bottom was continental rather than oceanic.

Seismic-refraction and reflection studies were made at 25 locations between the Marshall Islands and San Diego. Two were in shallow water at Alexa Bank and Nukuhiva; the remainder were in sea depths ranging from 1000 fathoms in the Tonga Islands to more than 5000 fathoms in the Tonga Trench. More work is required before final reduction of data, but some of the tentative conclusions are:

(1) No travel-time curves of continental type were observed inside or outside of the andesite line.
(2) The "characteristic" crustal velocity averaged 6.8 km/sec.
(3) At 19 of the deep-water stations, Mohorovicic velocities of more than 8 km/sec were reached. Except at the Tonga Trench, Moho depths were 5–10 km beneath the sea floor. The four exceptions were in the shallower depths of the Fiji-Tonga and the Easter Island Rise areas, where velocities between 7½ and 8 km/sec were reached.
(4) Sedimentary fill in the Tonga Trench appeared to be no more than a few hundred meters. The rock forming its bottom had a velocity of about 6 km/sec, and the Moho was estimated to be about 15 to 20 km deep.
(5) The 5 km/sec layer observed on the MID-PACIFIC Expedition of 1950 was more prevalent on CAPRICORN. Its thickness ranged from negligible to 3 or 4 km.

KERN COUNTY AFTERSHOCKS; SECOND REPORT

C. F. Richter
California Institute of Technology, Seismological Laboratory, Pasadena, Calif.

Aftershocks of the Kern County series continue (January 25, 1954) in a sharply limited area, the boundaries of which were established by the end of July 1952. The few exceptions indicate possible extension of activity northeastward. Meanwhile, activity in the remainder of southern California has recovered from a very low level to the usual norm.

During the last 3 months of 1952 there were 11 Kern County shocks in the magnitude range 4.0–4.9 inclusive; during 1953 there were 18 in this range, and 198 in the range 3.0–3.9 inclusive.

No shock of the series exceeded magnitude 4.9 from August 22, 1952, to January 12, 1954. At 23:33:49 G.C.T. on the latter date, a shock of magnitude 5.7 to 6.0 originated at a hypocenter nearly indistinguishable from that of the main shock of 1952; differences of arrival times of the two shocks at 13 stations are the same within 0.3 sec., and readings for three additional special stations also are in excellent agreement. On January 12–14 numerous smaller aftershocks occurred, some from nearly the same epicenter (35° 00′ N. 119° 01′ W.) and others from about 35° 01′ N. 119° 05′ W.

DEUTERIC DIFFERENTIATION OF GABBRO AT MOUNT SHERIDAN, WICHITA MOUNTAINS, OKLAHOMA

Forbes Robertson
Department of Geology, University of Washington, Seattle, Wash.

On the flanks of Mount Sheridan, the top of a sill-like gabbro intrusion in granite is well exposed. The intrusive relation of the gabbro to the Lugert granite is clearly shown by a chilled basaltic margin and small basaltic apophyses and dikelets in the granite. Solutions from the gabbro penetrated the granite to some degree and produced small replacement clusters of hornblende and biotite in the granite.

The chilled border is about 1 foot thick. Below it, the upper 30 feet of the sill is differentiated from the top down through adamellitic, granodioritic, and tonolitic facies into the normal gabbroic rock. About 150 feet of the gabbro is exposed at the locality sampled. Nearly vertical, coarse, pegmatitic zones and albitic veins occur in the gabbro.

Diabasic texture, beautifully developed in the gabbro, is preserved in relic form throughout the differentiated layer. Deuteric emanations were primarily responsible for the transfer of silica and potash to the top of the intrusion where early-formed minerals were replaced and reconstituted.

The following mineralogical changes occur in the differentiated layer: quartz and potash feldspar are conspicuous and abundant in the upper portion, and absent in the gabbroic facies; plagioclase ranges from about Ab_{60} to Ab_{45}; pyroxenes have mineralogical and compositional variations. Other mineralogical changes are considered in detail.

METHOD FOR EXPRESSING THE SEISMICITY OF A REGION

Pierre St. Amand
California Institute of Technology, Seismological Laboratory, Pasadena, Calif.

Specific seismicity may be defined as the square root of the energy, per unit area per unit time, released by the earthquakes of a given region. This may be found by reducing individual earthquakes to an equivalent number of earthquakes of a given magnitude. The sum of these for all earthquakes in a region may then be formed.

Maps drawn with iso-seismicity contours are an aid in visualizing the seismicity of an area and give an indication of the relative tectonic activity of different regions. Examples taken from the Kern County, California, aftershock sequence are used to illustrate the method.

TECTONICS OF ALASKA AS DEDUCED FROM SEISMIC DATA

Pierre St. Amand
California Institute of Technology, Seismological Laboratory, Pasadena, Calif.

Alaska is a region of high tectonic activity. The activity is concentrated along two Pacific-type arcs, one on the mainland formed by the Alaska Range, the other, the Aleutian Island Arc. The two arcs intersect south and west of Mount McKinley. The Alaska Range arc is convex northward and probably represents a southerly dipping thrust. The Aleutian Arc is convex southward and probably represents a northerly dipping thrust. The region of intersection must be undergoing left-hand shear.

The interior valley of Alaska, the Tanana Valley, may be an incipient trench such as those on the convex side of Pacific type arcs. Geomorphic evidence indicates considerable subsidence since Pleistocene.

The "Denali" fault is perhaps the expression of the northern edge of the Alaska Range thrust sheet. On geologic and geomorphic evidence, this fault may be traced from Mt. McKinley (Denali) eastward through the Alaska Range to the Canadian Border. It can be traced from the Border through Lynn Canal on geomorphic evidence and into the ocean on oceanographic evidence. Earthquake epicenters mark the entire path.

The Alaska Range probably represents the northern edge of a block of which the San Andreas fault system is a gigantic tear fault.

The region north of the Yukon-Tanana upland is relatively free of earthquakes.

BERMUDA T PHASES WITH LARGE CONTINENTAL PATHS

D. H. Shurbet
Lamont Geological Observatory (Columbia University), Palisades, N. Y.

A short-period arrival on records of the Bermuda-Columbia seismograph station is identified as a *T* phase with a path of propagation consisting of land paths up to 51° preceding 14° of water path. The travel time of this phase can be accounted for if the energy travels as the *P* phase over the land path and as the *T* phase over the ocean path. Background noises in the Sofar channel do arise in some cases from earthquakes as much as several thousand miles inland.

BASALT COLUMN RINDS CAUSED BY DEUTERIC ALTERATION

Harry W. Smedes and Andrew J. Lang, Jr.
U. S. Geological Survey, Spokane, Wash.; University of Wichita, Wichita, Kans.

A late Tertiary columnar olivine basalt flow in south-central Oregon is characterized by a narrow, dark rind zone around each column. This rind, which was at first attributed to chilling, represents a zone of deuteric alteration caused by volatiles from the flow escaping toward the joint cracks. Locally the volatiles were trapped within the core of the columns and produced altered patches. The altered patches and rind zone are characterized by the presence of chlorophaeite, a hydrous mineraloid of deuteric origin. Elsewhere, the rock is fresh.

The joint cracks are believed to represent loci of reduced pressure toward which the volatile materials streamed from the interior of the columns. Volatiles were trapped only locally in the core but uniformly in thin zones around the columns, where they proceeded to convert olivine and glassy base into chlorophaeite and, sometimes, into carbonates and chlorophaeite.

Two earlier reports of joint crack control of deuteric alteration are cited. However, in both cases the rock adjacent to the joint cracks was fresh, and the rock farther away was highly altered. This condition is the reverse of that observed by the present writers.

X-RAY STUDY OF FERRIERITE FROM BRITISH COLUMBIA

Lloyd W. Staples
University of Oregon, Eugene, Ore.

Ferrierite was named and described in 1918 by R.P.D. Graham. The Kamloops Lake locality is its only reported occurrence. An X-ray study of the mineral indicates cell dimensions: $a_o = 19.12 \pm 0.06$ Å., $b_o = 14.14 \pm 0.03$ Å., $c_o = 7.48 \pm 0.02$ Å., and an orthorhombic body-centered lattice. The choice of axes is Graham's and departs from the conventional orthorhombic orientation in which $c < a < b$. The following space groups are compatible with the X-ray observations: Immm, I222, Imm2, $I2_12_12_1$. Tests for piezoelectricity in liquid nitrogen were negative or inconclusive. From the cell-content calculation a general formula of $(Na, K)_4Mg_2(Si_{30}Al_6)O_{72}(OH)_218H_2O$ is indicated. Although ferrierite, because of its high magnesium content, is unusual among zeolites, rehydration and other tests point to a tectosilicate framework structure rather than a sheet structure.

STRUCTURAL EFFECTS OF THE 1952 SOUTHERN CALIFORNIA EARTHQUAKES

Karl V. Steinbrugge and Donald F. Moran
Pacific Fire Rating Bureau, 914 Merchants Exchange Bldg., 465 California St., San Francisco, Calif.

This paper is principally in the form of colored slides showing structural damage. Earthquake effects to masonry structures specifically designed to resist a high degree of shock are of special interest. In this regard, the performance of public schools is noteworthy. The damage to multi-story structures 80 or more miles from the epicenter indicates that further study of this type of structure is needed.

MARSUPIALS FROM THE MARINE CHELTENHAMIAN STAGE (LATE TERTIARY) OF VICTORIA, AUSTRALIA

R. A. Stirton
Museum of Paleontology, University of California, Berkeley, Calif.

A few fossil mammalian remains found as surface specimens on the beach of Beaumaris in Victoria, Australia, evidently have eroded out of the Sandringham sands. The beds from which they were derived have been referred to the "Cheltenhamian stage" of Singleton. Singleton (1941), Gill (1949), and Glaessner (1951) refer this stage to the late Miocene, and Crespin (oral communication) called it early Pliocene.

Part of a right maxillary, bearing M^3, M^4, and the posterior moiety of M^2, and an abraded left P^3 represent a lower crowned and smaller diprotodont than the species related to it in the new Palankarinna fauna in South Australia. The anterior part of a mandible of another ?diprotodont may represent a new subfamily. A fragment of a wombat and another of a wallaby evidently have come from the overlying Pleistocene.

This offers evidence for a marine-continental correlation. The specimens are on loan from the National Museum in Melbourne.

CONTINENTAL STRATIGRAPHY AND LATE TERTIARY MARSUPIALS IN SOUTH AUSTRALIA

R. A. Stirton and G. D. Woodard
Museum of Paleontology, University of California, Berkeley, Calif.

Early Tertiary continental deposits of Central Australia designated originally as "Desert Sandstone" and renamed the "Eyrian Series" by David and Woolnough (1926) are described from an area east of Lake Eyre, South Australia.

Escarpments reveal lacustrine sediments, probably of early Pliocene age, unconformably above the earlier Eyrian rocks. Teleost bones, lung-fish teeth, chelonian fragments, crocodilian teeth and scutes, and crayfish gastroliths occur in these lacustrine clays. An arenaceous channel deposit cutting into one of the clay units has yielded a new Tertiary marsupial fauna which includes abundant re-

mains of a new genus of kangaroo, part of the lower jaw of a bandicoot, and two new genera of diprotodonts. A phascolarctid maxillary with one molar was found at a lower level.

The exposures along Cooper's Creek, about 12 miles to the north, reveal flood-plain and channel deposits possibly of the same age. These beds are dominantly arenaceous with some sandy clay units. A dolomitic limestone occurs in both sections.

TOTAL REFLECTION OF TRANSVERSE PLANE WAVES

Burl A. Tuller
Dept. of Geol. Sciences, Univ. of California, Berkeley, Calif.

Total reflection of transverse plane waves, at a free surface, is treated by two methods. The first technique uses the standard assumption of simple harmonic motion. On this basis the resultant displacement is analyzed with respect to the individual phases—that is, the contributions of incident *SV* and reflected *SV* and *P* are isolated and plotted as functions of the angle of incidence. Beyond the critical angle of reflections (*ic*), the contribution of reflected *SV* alone is linear, and its amplitude equals the incident wave; however, there is a phase shift between them. Combined effects of the incident and reflected *SV* produce a direct elliptical displacement except at an incidence of 45°, where it reduces to vertical motion. Reflected *P* also contributes direct elliptical motion except at 45°, where it vanishes. Resultant motion due to the three phases is direct elliptical from *ic* to 45° where it reduces to vertical motion; however, beyond 45° the motion is retrograde elliptical.

The second method employs a pulse in the form of the Dirac delta function. Contrary to the first method, this latter technique indicates that the amplitude of the reflected *SV* does not equal the incident amplitude. Also the axes of the ellipses, because of a combination of all the phases, are tilted; whereas in the first method they are not.

The correlation of elliptical motion as a function of distance with actual earthquake data is attempted.

GLAUCOPHANE SCHISTS ASSOCIATED WITH GREENSCHISTS IN THE SAUK RIVER AREA OF THE NORTHERN CASCADE MOUNTAINS, WASHINGTON

Joseph A. Vance
University of Washington, Seattle, Wash.

Prominent in the series of regionally metamorphosed Carboniferous rocks of the Sauk River area is a 25-mile-long belt including glaucophane schists associated with greenschists. The greenschists are characterized by the mineral association epidote-actinolite-albite-chlorite, the glaucophane schists by epidote-glaucophane-chlorite-(quartz); rocks transitional between these types are common and contain glaucophane with isomorphous admixture of actinolite. Lesser amounts of stilpnomelane, muscovite, carbonate, and actinolitic hornblende are sometimes present. The glaucophane schists and the greenschists are closely interlayered and transitional and despite differing mineral associations do not seem to differ much in bulk composition. Both rock types have been derived from the same parent material, probably andesitic flows. A very fine metamorphic-differentiation-produced banding is superimposed on the broader interlayering of glaucophane schists and greenschists. Of interest, though local, is the occurrence of a thin Na-Fe amphibole- and aegerinaugite-bearing quartzite intercalated within greenschist-glaucophane schist beds. The diagnostic mineral assemblage of the greenschists places these rocks and the associated glaucophane schists in the greenschist facies, in the warmer part as the occasional occurrence of actinolitic hornblende indicates. The presence of chlorite, stilpnomelane, and albite in isograde intercalated sericite-quartz phyllites indicates temperatures still within the chlorite zone. Confirming the placing of the glaucophane schists in the warmer part of the greenschist facies is the sequence of progressive metamorphism found by Misch northeast of the area in which amphibolites replace glaucophane schists and greenschists very shortly after the appearance of biotite in associated argillaceous rocks.

OBSERVATIONS ON ROCK GLACIERS IN THE ALASKA RANGE

Clyde Wahrhaftig
U. S. Geological Survey, 4 Homewood Place, Menlo Park, Calif.

The rock glaciers in the Alaska Range are lobate or tonguelike mounds of rubble occupying cirque floors and alpine valleys. They head in talus cones of blocky debris, commonly granite, greenstone, and porphyry. The upper surface has longitudinal roll-like ridges and arcuate rolls parallel to the front. It has coarse lichen-covered fresh cracks. The fronts of active rock glaciers are steep and free of all vegetation. Some rock glaciers head in small ice glaciers, others in depressions left by recent ice glaciers. Many slope down evenly from talus cones. Some are in cirques adjacent to cirques containing debris-poor ice glaciers. Some cirques have rock glaciers of two ages younger than late Wisconsin: an older, now dissected and overgrown; and a younger advancing into gullies dissecting the older.

Measured movement of a rock glacier near Windy is 2½ feet annually along the medial line, decreasing to 1 foot at the edges. The center of the front moves forward 2 feet per year. Growth of the rock glacier, therefore, is by forward motion of the entire mass, probably through glacierlike motion of interstitial ice formed by water freezing in talus.

Rock glaciers are believed to arise in permafrost regions from talus so thick that its weight forces interstitial ice to flow. They are believed to be the forerunners of a new ice glaciation in semiarid regions.

SAMPLING IN BIOGEOCHEMISTRY

Harry V. Warren, Robert E. Delavault, and John A. C. Fortescue
Department of Geology and Geography, University of British Columbia, Vancouver, B. C.

In previous reports the writers have stressed the importance of sampling in biogeochemical work. This paper emphasizes the desirability of accurate sampling and, with the aid of diagrams, demonstrates that it is essential not only to compare organs of the same age, but that to achieve optimum results it is necessary to select that organ which responds best to the element being investigated.

Furthermore, anomalies can best be detected if one remembers that the tops and sides of trees may have significant variations in their content of some metals. The response of tips of one season's growth or less in contrast to that of older growth may vary widely with different metals, notably zinc and molybdenum.

Data suggest that some species reflect more readily geochemical anomalies of a specific metal than do others; this emphasizes the importance of selecting suitable species for biogeochemical studies.

ABSTRACTS OF PAPERS SUBMITTED FOR THE MEETING IN COLUMBIA, SOUTH CAROLINA, APRIL 15, 16, 17, 1954

NORTH CAROLINA COASTAL PLAIN FLOOR 1953

E. Willard Berry
Duke University, Durham, N. C.

Between 1948 and 1954 five holes have been drilled for oil in North Carolina. Edgar Basemore No. 1 near Ahoskie (Hertford Co.) which encountered basement at 1285 feet; Cadco No. 1 about 6 miles north of Holly Ridge (Onslow Co.) with basement at 1450 feet; Cadco No. 2 about 1½ miles north of No. 1 found basement at 1343 feet; Hofmann (?) No. 1, 1 mile east of U. S. Route 17 near fire tower in Hofmann Forest (Onslow Co.) found basement at 1570 feet; du-Grandlee Foreman No. 1 about 9 miles north of Elizabeth City (Camden Co.) reached a total depth of 6421 feet, but the samples are so poor that it is impossible to determine if it encountered basement or not. All the samples are poor, and no electric log was run. Except for this last hole they all fall in the picture as shown in 1948. Du-Grandlee Foreman No. 1 should have encountered basement at around 3000 feet on past contours. There are no holes within 50 miles, and as the samples are useless we cannot count it. The contours drawn over from Virginia show conditions as depicted on the author's 1948 map.

CLEAVAGE TENDENCIES IN QUARTZ

F. Donald Bloss
Department of Geology and Geography, University of Tennessee, Knoxville, Tennessee

Specimens of crystal, rose, and milky quartz were crushed both at room temperature and in the 650–700°C range. Slide mounts of the 100–200 mesh fragments were examined on the universal stage to determine the angle between the optic axis and the normal to the surface on which the grain rested.

The resultant data for both temperatures show a definite crystallographic control with a maximum frequency occurring near the 52° angle and a lesser one near the 90° angle. For low quartz the first peak is attributed to the tendency of quartz to cleave parallel to the *r* and *z* rhombohedra, the second to its lesser tendency to cleave parallel to a prism face. For high quartz the peak at 52° is interpreted as an expression of cleavage parallel to the corresponding unit pyramid. The inferior prismatic cleavage was again expressed by a lesser peak.

The 52° peak for high quartz is significantly higher than that for low quartz. Thus the pyramidal cleavage in high quartz appears superior to the corresponding positive and negative rhombohedral cleavage of low quartz. Unfortunately the method does not permit separation of the effects of the positive rhombohedral cleavage from those of the negative rhombohedral cleavage for low quartz.

The different varieties of quartz all showed the same major cleavage characteristics both in the high and low modifications. However, the rose variety showed a slightly greater tendency toward prismatic cleavage for both temperatures, perhaps because of the existence in it of numerous inclusions parallel to the *c* axis. The milky quartz also showed an individualistic tendency toward a third very subsidiary peak in the 70–75° range for both temperature modifications.

The observations of Ingerson and Ramisch (1942) that fragments of crushed quartz were more frequently elongate perpendicular to the *c* axis than parallel to it are possibly explained by the relative superiority of the rhombohedral over the prismatic tendency to cleave.

Rowland's observations of the angle between the optic axis and the pole to the maximum projection area for numerous quartz grains disaggregated from several Pennsylvanian sandstones closely parallel the present observations on cleavage tendencies. This parallelism suggests that the response of quartz grains to abrasion is strongly controlled by the cleavage tendencies.

HIGH-ALUMINA MINERALS IN THE VOLCANIC-SLATE SERIES OF NORTH CAROLINA

Sam D. Broadhurst and Richard J. Councill
North Carolina Department of Conservation and Development, Raleigh, N. C.

In the Volcanic-Slate series of North Carolina, andalusite, topaz, and diaspore have been discovered in some pyrophyllite deposits. An investigation is being conducted to determine the abundance, origin, and commercial possibilities of these high-alumina minerals. Kyanite and sillimanite, known to occur in limited amounts, are also being studied.

Reconnaissance work shows that deposits in which high-alumina minerals occur have similarities of structure, shape, and occurrence, differing principally in volume and in the relative abundance and ratio of high-alumina minerals. In the large pyrophyllite deposits, andalusite is the predominant high-alumina mineral. In places topaz occurs in moderate amounts, and diaspore is not common. Small amounts of pyrophyllite occur with the kyanite, but none has been found with sillimanite. Associated minerals include quartz, sericite, clay minerals, chloritoid, pyrite, hematite, and lazulite.

Like pyrophyllite, the high-alumina minerals are products of metasomatic replacement, having formed at intermediate to high temperatures by the action of ascending solutions which permeated acid tuffs and breccias. Deposits are confined to narrow zones of strong fracture which generally parallel regional structures.

High-alumina minerals usually constitute less than 10 per cent of a deposit, and probably they cannot be separated economically from the associated minerals. However, their presence in marginal pyrophyllite deposits raises the alumina content to a point where the ore can be marketed. The discovery of these high-alumina minerals has tripled the known reserves of pyrophyllite ore in North Carolina.

GEOLOGIC RELATIONS IN AND BETWEEN THE ESMONT AND ARVONIA SLATE DISTRICTS, VIRGINIA*

William R. Brown and Harvey C. Sunderman

The west-central Piedmont of Virginia includes part of the granitic core and the southeastern flank of the Catoctin-Blue Ridge anticlinorium and the relatively less metamorphosed rocks of the James River synclinorium. In the central Piedmont, Ordovician Arvonia slate lies in another synclinal structure.

In the Covesville quadrangle of the western Piedmont, granitic basement rocks are overlain unconformably by the Lynchburg formation, and this in turn by Catoctin greenstone. The Catoctin dips southeastward beneath the Candler formation (and its Esmont slate facies) of the James River synclinorium. The Candler outcrop belt is continuous southeastward to a belt of submarine (?) greenstone volcanics in the western part of the Dillwyn quadrangle, interpreted to be Catoctin greenstone re-exposed on the west limb of a large anticline. These greenstones are again exposed on the east flank of this structure. The mica-quartz schists in the intervening core of the anticline, called "Peters Creek formation" by Stose and Stose, are probably a facies of the Lynchburg formation. Greenstones of the eastern outcrop belt underlie, in part, the Arvonia slate. Since the Candler formation lies upon Catoctin greenstone and Arvonia slate lies upon probable Catoctin, the Candler and Arvonia formations may be equivalent in part.

An increase in the degree of metamorphism in the "knotted" slate portion of the Arvonia slate with approach to the Columbia granite appears to indicate that this granite is younger than the slate, rather than older as previously thought.

ORIGIN OF VERMICULITE AT TIGERVILLE, SOUTH CAROLINA

B. F. Buie and Otis F. Stewart
Dept. of Geology, University of South Carolina, Columbia, S. C.

Field relationships at the Tigerville deposit of the Zonolite Company show clearly that the vermiculite resulted from alteration of biotite by meteoric water. These relationships include: (1)

*Presented with the permission of the State Geologist of Virginia

gradual increase in firmness and darkening of the vermiculite downward from the surface and toward masses of biotite; (2) absence of biotite at the surface and presence at moderate depth (15 to 20 feet); (3) presence of residual masses of biotite surrounded by vermiculite which has developed along joints and slippage planes.

The vermiculite contains 5 to 20 per cent of microcline, hornblende, and diopside, considerably weathered. The biotite masses within the vermiculite contain the same minerals, relatively fresh and unweathered. Except for differences accountable for by weathering, the accessory minerals in the vermiculite and in the biotite are identical.

Chemical analyses of the biotite and of vermiculite from different depths indicate that the change from biotite to vermiculite is gradational, accompanied by an increase in H_2O and Fe_2O_3 and a decrease in FeO, Na_2O, and K_2O.

The biotite appears to have been formed from a mass of diopside by successive alteration to hornblende and to biotite. Hydrothermal activity, possibly related to the numerous small bodies of pegmatite, may account for the biotite.

FULLER'S EARTH INDUSTRY IN FLORIDA

James L. Calver
Florida Geological Survey, Tallahassee, Fla.

The earliest discovery, in the United States, of clay suitable for fuller's earth was made in 1893 at Quincy, Gadsden County, Florida. Since 1895, these clays of middle Miocene age have been mined and processed at Quincy and in other localities in Gadsden County, as well as in Decatur County, Georgia. The Florida-Georgia fuller's earth district in 1941 produced 44 per cent of the quantity and 51 per cent of the value of the fuller's earth mined in the U. S. In 1952, the district produced 64 per cent of the quantity and 70 per cent of the value of fuller's earth mined in the U. S. From the beginning of mining in 1895, until 1942 nearly all the fuller's earth produced was consumed in filtering and decolorizing mineral and vegetable oils. Since 1942 new uses for these clays include rotary-drilling muds, absorbents for oily floors, carriers for insecticides and fungicides, and fillers for certain plastics. These new processes consumed 60 per cent of the 1952 production.

SEDIMENTARY STUDIES IN THE SHENANDOAH VALLEY OF VIRGINIA

Dorothy Carroll
U. S. Geological Survey, Washington 25, D. C.

An investigation of the mineralogical properties and mechanical composition of soils, river sands, alluvium, and rocks gives detailed information concerning the materials involved in erosion and river development. Samples were collected from several localities in the Middle River basin selected to provide information on the rocks being eroded, the soils being formed, and the alluvium being deposited.

The mineralogy of the following formations is described: Chemung formation and Brallier shale of Late Devonian age; Martinsburg shale, Beekmantown dolomite, and Lenoir limestone of Ordovician age; Conococheague limestone and Elbrook dolomite of Cambrian age. The Chemung, Martinsburg, Conococheague, and part of the Elbrook contain distinctive, though restricted, insoluble residues and particularly distinctive heavy minerals. Variations in content of quartz, feldspar, and clay minerals are important. The mineralogy of the sands from river beds varies according to the rocks through which the river flows; for example, when the stream cuts through the Martinsburg shale very small zircon grains are added to the bed load; euhedral quartz crystals are added from the Beekmantown dolomite.

Detailed descriptions are given of a soil profile developed on the Lenoir limestone and on the Brallier shale.

Mechanical analyses of soils and alluvium give the size distribution of material that is being eroded. Residual soils have a high silt (50 - 2 micron grain diameter) content but very little sand. Coarse chert accumulates in the soil above cherty limestones and dolomites.

These investigations were undertaken to provide background information for geomorphological

studies by John T. Hack and the writer. The clays present in rocks, alluvium, and soils will be described in another paper by John C. Hathaway.

APPALACHIAN PROFILE IN MARYLAND

Ernst Cloos
The Johns Hopkins University, Baltimore, Md.

A section across the Appalachians in Maryland consists essentially of the following three major divisions: (1) a belt of shallow-flexure folds between the Appalachian Front and the tectonite frontier, (2) the South Mountain-Blue Ridge anticlinorium, and (3) the Piedmont crystallines.

(1) The belt of flexure folds almost coincides with the time honored Valley and Ridge Province. There is no regional cleavage, but the cleavage fans in separate folds. Fold axes are horizontal or plunge gently. Lineations parallel the fold axes. The folds may be overturned to the east or west, and many are symmetrical. The structures generally resemble those of the Jura Mountains.

(2) In the South Mountain-Blue Ridge anticlinorium all folds are asymmetrically overturned to the west, and the area is dominated by a most intense eastward-dipping regional cleavage. Within the cleavage is a very distinct down-dip lineation generally perpendicular to the fold axes and the strike of the cleavage. The basement participates in the movement, shows the same cleavage and lineation, and protrudes upward into anticlinal cores.

(3) The piedmont crystallines become coarser and more intensely altered from west to east. Axes are gentle or steep. Lineation is steep at many localities. Intrusions are widely distributed and form rising centers. Migmatization, granitization, and intense metamorphism seem related to domes.

Movement components seem to be horizontal in (1), become inclined upward in the Blue Ridge (2), and are predominantly upward in the crystalline axis (3).

The author suggests that partition of the Appalachians into physiographic provinces is outdated and should be supplanted by functional partitions which are related to structural belts: (1) zone of true folding and thrusting; (2) zone of regional cleavage and northwestward overturning; and (3) zone of rising crystalline intrusions in the broadest sense—this zone may also be termed the crystalline axis of the Appalachian tectogene.

STRATIGRAPHY OF THE CHATTANOOGA BLACK SHALE IN THE FLYNN CREEK STRUCTURE, JACKSON COUNTY, TENNESSEE*

Stephen G. Conrad, Robert T. Elmore, Jr., and Stuart W. Maher
University of Tennessee, Knoxville, Tenn.

In the Flynn Creek structure, Jackson County, Tennessee, the Dowelltown, or lower, member of the Chattanooga black shale is greatly overthickened. Studies further indicate that the lower gray-black shale, or "Unit A," of the Dowelltown member is more overthickened than the upper gray shale, or "Unit B." Immediately outside the structure the Dowelltown member ranges from 7.0 to 9.0 feet in thickness. Within the structure, a maximum thickness of 166.40 feet of Dowelltown was measured. The Gassaway, or upper, member of the Chattanooga, retains its normal thickness across the structure.

The presence of the bentonite within the structure is significant in that this is the northern limit of the bentonite. On the northern, northeastern, and western sides of the structure the bentonite is absent in all observed outcrops of the shale. The bentonite is believed to have been preserved within the structure because of compaction, or settling, of the sediments.

The writers believe that the Flynn Creek structure represents a pre-Chattanooga basin with at least 200 feet of relief. This basin was filled largely by gray-black or "A" type sediments. The remainder of the basin was filled with gray or "B" type sediments, and enough compaction, or settling, took place to preserve the bentonite. By Gassaway time a relatively smooth surface was present on which normal late Chattanooga sedimentation took place.

* Courtesy of the U. S. Atomic Energy Commission

SEDIMENTATION CYCLES IN THE POCONO OF WEST VIRGINIA

Jesse L. Dally
Dept. of Geology, West Virginia University, and West Virginia Geological Survey, Morgantown, W. Va.

The Pocono rocks in West Virginia consist of (1) cross-bedded sandstones which contain coquinite zones, clay galls, and scattered conglomerates; (2) interbedded, thin, thin-laminated siltstones and silty argillites; and (3) dark-gray, thin-laminated argillites. An occasional impure coal is present. These lithologies are repeated in vertical sequence, with the cross-bedded sandstones and interbedded siltstone and argillite zones most common. These lithologic units appear to correspond almost exactly to the undathem, clinothem, and fondothem of Rich (1951).

At Caldwell, Greenbrier County, West Virginia, an excellent exposure in a railroad cut shows clearly the nature of the upper Pocono. At this locality it contains several cyclothems, the lowest of which includes representatives of all 10 members of the ideal cyclothem. The sandstone member of this cyclothem is at least 90 feet thick and is a typical undathem. Northeast and southwest along the belt of exposure, cyclothems are not present. Cyclothems contain deposits formed in transitional environments, and the abnormal thickness of the associated marine undathem indicates that sediment was offered to the epeiric sea so rapidly and in such volume that it accumulated above water level. The geographically restricted occurrence of the transitional environments rules out fluctuations in sea level as an explanation of their origin. The evidence indicates the presence of the mouth of a major river which appears to have furnished the bulk of the Pocono sediment, at least in southeastern West Virginia.

ANALYSIS OF THE CLAY FRACTION OF SOILS FROM THE GREEN SPRINGS AREA, LOUISA COUNTY, VIRGINIA

James L. Eades
Virginia Department of Highways, Charlottesville, Va.

Analysis of the clay fraction of 75 samples of soils derived from igneous rocks located in a small valley in Louisa County of Virginia reveals: (1) a number of soil-forming agencies must be present to give the same clay minerals, (2) parent material is an important factor in the composition of the clay fraction, (3) soil types as mapped in this area by the Soil Conservation Service contain comparable clay fractions.

AGE OF THE SERPENTINITE BELT OF THE CAUCASUS RANGE

N. Efremov
1061 Intervale Ave., New York, N. Y.

The serpentinite belt of the Caucasus is about 300 km long and consists of over 60 massifs studied by the author. The author's observations fundamentally change the concept concerning the age of the Caucasian serpentinites. These concepts were based on the fact that serpentinite pebbles were found neither in the Permian nor in the Carboniferous conglomerates of the Caucasus. At the same time an eruptive contact of serpentinites with Permian was reported. Thus the Caucasian serpentinites were referred either to the Permian (or even Post-Permian) or to the Caledonian (or even to the Precambrian). The author's investigations have shown that in the conglomerates of the Middle Carboniferous in the basins of the Kefar, Kefar-Agur, Zaguedan, and Khudes rivers serpentinite pebbles are encountered everywhere. On the other hand, the serpentinites break through the deposits of sandstones and clayey schists of the so-called Karachai series of the Lower Carboniferous. Thus it is possible to determine very narrow age limits for the majority of the Caucasian serpentinites *between the Lower and the Middle Carboniferous*. The simultaneity of the intrusions of the Caucasian serpentinite belt is in good agreement with the concept of H. H. Hess concerning the world's serpentinite belts.

CERTAIN STRATIGRAPHIC PROBLEMS IN THE WARRIOR BASIN*

Rizer Everett
District Geologist, The Carter Oil Co., Jackson, Miss.

The Warrior Basin of northeast Mississippi and northwest Alabama has experienced moderate wildcat drilling activity since the completion in February 1952 of the Union #1 Sanders as a commercial gas well. Some of the stratigraphic problems presented include: the lateral gradation of lithology and permeability of Chester sands, the difficulties of correlating the Chester section, and the difficulties of recognizing commercial sands. The solutions to the problems will be worked out as decline data are obtained from the newly discovered gas fields and as more wildcat wells are drilled in the Basin.

INFOLDED METASEDIMENTS NEAR THE AXIAL ZONE OF THE CATOCTIN MOUNTAIN-BLUE RIDGE ANTICLINORIUM IN VIRGINIA†

Edwin O. Gooch
Virginia Geological Survey, Charlottesville, Va.

A belt of metasedimentary rocks about 60 miles long and from half a mile to 2 miles wide occurs in the northwestern Piedmont of Virginia, near the axial zone of the Catoctin Mountain-Blue Ridge anticlinorium. The core of this anticlinorium is a complex of granitoid and gneissoid rocks. Overlying this complex on the eastern limb of the anticlinorium is the Lynchburg formation, and on the western limb the Swift Run formation.

The writer interprets the strip of metasedimentary rocks as a series of infolds in the basement complex. Four separate infolds occur, two large and two very small. The infolds are isoclinal and overturned toward the northwest in the southern part of the structure but become more open in the northern part. Reverse faulting interrupts the continuity of the folds in places.

The Lynchburg formation, the Swift Run formation, and the metasedimentary rocks were all derived from the basement complex. Recent theories are that the Lynchburg formation overlaps the basement complex from east to west and that the Swift Run represents the thinned western edge of the overlap. Thus the Lynchburg and Swift Run are considered equivalent. Geographically, the belt of metasedimentary rocks is about half way between the Lynchburg formation on the east and the Swift Run formation on the west. The writer correlates the metasedimentary rocks with the Lynchburg-Swift Run formation.

GEOLOGY OF HART COUNTY, GEORGIA

Willard H. Grant
Geology Department, Emory University, Emory University, Ga.

Hart County is situated in the northeastern part of Georgia on the South Carolina state line where the confluence of the Seneca and Tugaloo rivers form the Savannah River.

Most of the rocks are either metasedimentary schists and gneisses or granitic rocks. The feldspathic amphibolite gneiss represents a third type of uncertain origin. The metamorphic grade is mainly in the amphibolite facies although local mineral assemblages characteristic of the epidote amphibolite facies exist. The metasedimentary rocks include biotite-plagioclase gneisses, sillimanite-graphite schists, sillimanite-garnet-mica schists and gneisses, and staurolite-mica schists. Small quantities of an amphibolitic quartzite occur interlaminated with the first three units. The contacts between these units are usually gradational. The granitic rocks are of two main types: a biotite granodiorite gneiss, and a feebly gneissic, texturally variable, muscovite granodiorite. Between the biotite granodiorite gneiss and the metasedimentary rocks is a migmatitic transitional zone.

Structurally the area is divided into two zones. One is characterized by folding of variable intensity. From south to north the trend of the fold axes changes from N. 20° E. to NW. An undulation

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at right angles to the major fold trend is notable. The second zone is a weakly developed northeast-trending shear zone characterized by local chloritization, fracturing, and elongation of grains in granitic rocks and sheared recumbent folds and striations in the metasediments. A systematic statistical relation exists between lineation and jointing. Petrofabric data confirm the field conclusions.

BASEMENT ROCKS OF PART OF TENNESSEE-NORTH CAROLINA BLUE RIDGE

Warren B. Hamilton
U. S. Geological Survey, Denver Federal Center, Denver, Colo.

Basement rocks have been investigated recently in part of the Blue Ridge province athwart the Tennessee-North Carolina boundary from Latitude 36° 15′ northward almost to the Virginia line. The basement rocks rest unconformably beneath Lower Cambrian clastics to the northwest; these basement rocks are thus known to be Precambrian, and their lithologies and structures can be compared with those of rocks elsewhere in the Blue Ridge and Piedmont provinces.

The oldest recognizable structures resulted from Precambrian intrusion and plutonism of existing rocks to form gneisses, migmatites, and massive granitic rocks (granodiorite to granite).

Subsequent deformation (during early Paleozoic time?) extensively sheared the plutonic rocks to mylonite gneiss and schist, and this activity was accompanied by retrogressive crystallization of minerals of the greenschist facies. The cataclastic foliation commonly dips gently southeast.

Orogeny during late Paleozoic time faulted and folded the basement rocks and locally crinkled mylonite schists and produced a fracture cleavage in gneisses; fold and crinkle axial planes and fracture cleavage dip steeply southeast. Late Paleozoic faults crosscut the cataclastic foliation and are marked by narrow zones of gouge.

Temperature was progressively lower from the first deformation to the third, so the results of each deformation can be distinguished. Where early Paleozoic deformation elsewhere in the Blue Ridge and Piedmont areas was accomplished at high temperature, the record of Precambrian deformation may have been obscured. Accumulating evidence suggests that in the southern Appalachians there may have been little or no high-grade metamorphism or plutonism in the late Paleozoic.

INVESTIGATION OF ALLUVIAL CLAYS IN THE SHENANDOAH VALLEY

John C. Hathaway
U. S. Geological Survey, Washington 25, D. C.

The clay-mineral compositions of several samples of alluvial material and source-area soils of the Middle River drainage basin of the Shenandoah Valley have been determined. Vermiculite-, mica-, and kaolin-type clay minerals occur in varying amounts. Parent material shows less influence on clay-mineral composition than does degree of weathering as suggested by position of the samples in soil profiles.

Vermiculitic clay of a mixed-layer character, possibly interstratified with chlorite and mica layers, seems to increase in importance with weathering. A decrease in hydrous mica usually accompanies the vermiculite increase. The kaolin minerals exhibit the least change.

"WELDED TUFFS" OF OREGON AND IDAHO: A HYPOTHESIS OF ORIGIN

Donald M. Hausen
Waterways Experiment Station, P. O. Drawer 2131, Jackson, Miss.

Silicic extrusives of questionable origin extend over many thousands of square miles in Oregon and Idaho. Deposits range from dacitic to rhyolitic in composition, in thickness from 5 to 350 feet, and commonly grade upward from lavalike material into obviously pyroclastic tuffs. Gas-charged lavas apparently erupted from both fissures and craters during Miocene and Pliocene times, and their association with plateau basalts in the region suggests a differentiated magma as their common source.

Peculiar fluxionlike structures resembling collapsed pumice are displayed by these rocks in thin section. The term "welded tuff" has become popular in this country along with the connotation of a pyroclastic origin for these deposits; current notions favor a "nuee ardente" type eruption.

Investigations have been made on the Dorena Welded Tuff along the Row River in Western Oregon. These investigations include thermal tests; petrographic examinations; orientation studies of biotite laths and pumice fragments; and analyses of water content, chemical composition, specific gravity, and sorting effects. Preliminary evidence suggests: (1) that at time of deposition many of these deposits were expanding lavas rather than condensing pyroclastics; (2) that emplacement was accomplished by lateral flowlike movement of material, not unlike that of a flowing lava; and (3) that the major portion of these deposits was never expanded by gases to the extent displayed in most pyroclastic material. For these reasons the term "welded tuff" may be misleading in that it falsely conveys the impression that these deposits are wholly tuffaceous.

CLAYTON FORMATION, AN IMPORTANT AQUIFER IN SOUTHWEST GEORGIA

S. M. Herrick
U. S. Geological Survey, 11 Hunter Street, S. W., Atlanta 3, Ga.

The paper deals with the subsurface stratigraphy and ground-water potentialities of the Clayton formation in southwest Georgia. Opinions and conclusions are based on two subsurface sections. Study of well samples from selected wells along the section noted gives information on the stratigraphy and sedimentation that is of economic importance in relation to utilization of ground water in this part of the State.

In general, Coastal Plain sediments in southwest Georgia thicken coastward and at the same time show hydrologically significant facies changes. Sands that were good up-dip aquifers have silted up down the dip and are no longer valuable. Such is the case in the area described. Under these conditions limestone of the Clayton formation is the principal, and in certain parts of the area the only, available aquifer.

Data regarding the quality of water available from the Clayton formation are included.

GEOLOGY OF THE STONE MOUNTAIN AREA, GEORGIA*

Leo A. Herrmann
36 Main Street, Franklin, N. J.

The Stone Mountain area is located 15 miles east of Atlanta, Ga. The major rock types of the area are metamorphic gneisses and schists, migmatite (Lithonia gneiss), quartz monzonite (Stone Mountain granite), and diabase dikes. The migmatite and metamorphic rocks were deformed into northwest-trending transverse folds whose axes are perpendicular to a regional northeast-trending axis of deformation. A strong mica lineation, the axes of small folds, and elongated garnet porphyroblasts are oriented parallel to the axes of the transverse folds. Two sets of shear zones formed in the Lithonia gneiss during deformation: a pronounced set which trends about N. 20° E. and a less pronounced set which trends about N. 45° W.

The Stone Mountain granite discordantly intruded the metamorphic gneisses, schists, and migmatite. It developed flow structures including flowage foliation, mica fluctuation about an axis of rotation, and orientation of micaceous autoliths.

Potash-rich solutions and aplite veins intimately intruded the Lithonia gneiss, changing it into a migmatite. Relic bedding of the original gneiss is preserved in the form of quartz-rich garnetiferous layers which are usually conformable with the gneissic banding.

The metamorphic rocks are considered Precambrian. The solutions which migmatized the Lithonia gneiss apparently were introduced at an early stage of the Appalachian orogeny, during the final deformation of the metamorphic rocks. At a late stage of the orogeny, the Stone Mountain granite (Permian?) was introduced. Diabase dikes were intruded along northwesterly trending breaks in Triassic (?) time.

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CHEMICAL CHARACTER OF WATER IN THE IGNEOUS AND METAMORPHIC ROCKS OF NORTH CAROLINA

H. E. LeGrand
District Geologist, Ground Water Br., Water Resources Div., U. S. Geological Survey, Raleigh, N. C.

The igneous and metamorphic rocks of North Carolina vary considerably in chemical composition and, consequently, in solubility. Each major chemical type yields, from creviced or porous zones, ground water having a distinctive chemical character; enough contrast generally exists for chemical analyses of ground water to be an aid in geologic mapping where outcrops are scarce.

From the standpoint of their chemical character and that of the water derived from them, the rocks may conveniently be divided into two groups: (1) granite, granite gneiss, mica schist, slate, and rhyolite flows and tuffs, these rocks approximating granite in composition; (2) diorite, gabbro, hornblende gneiss, and andesite flows and tuffs, these rocks approximating diorite in composition. The granite group yields a soft, slightly acid water low in dissolved mineral constituents; the diorite group yields a hard, slightly alkaline water high in dissolved material.

Lithologic determinations based on the chemical character of ground water are generally reliable in regions of similar climate and topography. Anomalies in dissolved mineral constituents not due to differences in rock type, climate, or topography may indicate either abnormal structural conditions, resulting in abnormal rates of circulation of the water, or the presence of concentrated mineral deposits.

SANDY ZONES IN THE CHATTANOOGA OF THE EASTERN HIGHLAND RIM, TENNESSEE

Stuart W. Maher
University of Tennessee, Knoxville, Tenn.

Sandstone beds are more abundant than previously realized in both the Dowelltown (lower) member and the Gassaway (upper) member of the Chattanooga shale of the Eastern Highland Rim of Tennessee. Such beds increase in number and thickness from DeKalb County to the north and west toward Macon County.

A sandstone or conglomerate bed, normally present at the base of the Chattanooga shale, has been generally recognized. However, additional occurrences of sandstones are relatively common, throughout the Dowelltown member, and many exposures contain several such beds.

Over most of the Eastern and Northern Highland Rim, a persistent sandstone bed, called the Bransford sandstone by Campbell, occurs at the base of the Cassaway member of the Chattanooga. This bed is a useful stratigraphic marker in separating the Chattanooga into its two members.

A series of thinly laminated siltstones occur in the Gassaway member throughout the area studied. However, only a few occurrences of sandstone are known in the upper Chattanooga.

The present study suggests that these sands were deposited by relatively agitated water at shallow depths and are not lag concentrates.

This report is preliminary, and suggestions for further study are submitted.

APPLICATION AND USE OF THE GOLD PAN IN THE STUDY OF CRYSTALLINE ROCKS

John B. Mertie, Jr.
U. S. Geological Survey, Washington 25, D. C.

The gold pan is a useful tool in the mapping and economic evaluation of crystalline rocks. The principal application is in the study and sampling of weathered bedrock in regions where outcrops of hardrock are scarce or lacking. This technique was proposed and used by Orville A. Derby, an American geologist who worked for many years in Brazil. Similar results may be obtained by crushing, milling, and panning hardrock.

The crystalline rocks of the southeastern Piedmont province are commonly altered to a soft, co-

herent, untransported material known as saprolite, which may readily be sampled and panned. The structural features of the original hardrock are preserved in saprolite, but exact petrographic classification and correlation are impracticable, because most of the feldspars are decomposed to clayey products. Chemical data are similarly vitiated. Few of the heavy and semiheavy accessory minerals, however, are altered by weathering, and suites of such minerals are as useful as the feldspars in correlation and mapping.

The accessory minerals have other uses. Comparison of the minerals recovered from hardrock and its derived saprolite supplies information on relative weathering; such data are helpful in discriminating between metamorphic rocks of sedimentary and of magmatic origin. Moreover, the radioactive accessory minerals of magmatic rocks, notably zircon, monazite, and xenotime, are useful in determining by radiometric and spectrographic methods the relative and absolute ages of such rocks. Finally, the recognition of minerals of economic value, such as monazite, localizes the areas in which commercial placers may be found.

The technique of panning for accessory minerals is described; and the gold pan is shown to be a versatile and efficient tool, yielding separatory results that are comparable with those obtainable in the laboratory. The field methods used by the writer in processing and identifying the common accessory minerals are enumerated and briefly discussed.

BASEMENT CORES FROM GEORGIA, ALABAMA, AND FLORIDA

Charles Milton
U. S. Geological Survey, Washington 25, D. C.

A large number of oil wells have been drilled through sedimentary rocks of Tertiary and Cretaceous age into igneous and metamorphic rocks as well as into older sedimentary rocks of Paleozoic age. Core samples or cuttings have been obtained from many of these wells, and by means of thin-section study their petrographic character has been determined. Diabase and related basaltic rocks and rhyolite are found in many cores from southern Alabama, Georgia, and northern Florida. Associated with these are considerable thicknesses of arkose and graywacke and sediments of volcanic origin—tuffs and a h beds. Except for crystalline gneissic schist from the northern part of the drilled area—evidently an extension of the Appalachian metamorphic rocks beneath the Coastal Plain sediments—no unquestioned granitic rocks or crystalline schist are represented in the cores.

Lower Paleozoic sedimentary rocks exist beneath the southeastern Coastal Plain, but the age of the igneous rocks of the region is uncertain. The buried diabase rocks of Georgia presumably are Triassic, as are those cropping out in northern Georgia, and the diabase seems to grade into basaltic types, which in other parts of the world are associated with rhyolite.

Each well for which basement core or cutting is available has been examined, and the type of rock has been established. In many instances, this has necessitated revision of previously published identifications.

GEOLOGY AND OIL ACCUMULATION, CENTRAL GULF COASTAL PLAIN

Grover E. Murray
Louisiana State University, Baton Rouge, La.

Continental, marginal, and marine Mesozoic and Cenozoic sediments, 30,000–40,000 feet thick, constitute the Central Gulf Coastal Plain above Paleozoic and Precambrian basement rocks. Sparse data permit extension of the Ouachita and Appalachian trends of folding into the subsurface beneath the Central Gulf Region to within approximately 50 miles of each other. North and west of these structural trends, less deformed, primarily argillaceous and calcareous Paleozoic sedi.ents exist in the Warrior Basin of Alabama and Mississippi.

Mesozoic and Cenozoic deposits of the Central Gulf Coastal Plain constitute a great, roughly lenticular mass of intertonguing, primarily arenaceous, deltaic deposits and predominantly argillaceous-calcareous, marine sediments. Areas or sites of maximum deposition (depocenters) occur along the axes of thickness at approximately the centers of deltaic deposition during each sedimentary epoch. These individual deltaic masses coalesce to form elongate complexes resembling flattened link sausages.

Lithologically, the Jurassic is a clastic-evaporite sequence with locally developed reef limestones. Comanchean sediments vary from predominantly argillaceous-calcareous marine beds in the west to deltaic "red-bed" clastics in the east. Gulfian facies are mainly calcareous and argillaceous, but appreciable quantities of arenaceous materials occur in the eastern portion of the region. Tertiary strata consist of cyclic calcareous-argillaceous marine beds and arenaceous marginal strata. All exhibit greater structural deformation with increasing age.

Commercial production of oil or gas has been obtained from Ordovician, Mississippian, Pennsylvanian, Jurassic, Comanchean, Gulfian, and Tertiary strata. Reserves approximate 4 billion barrels of oil and 35 trillion cubic feet of gas. Major accumulations appear to be controlled both structurally and stratigraphically. Common structural types affecting accumulation are (1) domes and anticlines, faulted and unfaulted; (2) normal faults downthrown on the coastal side or on the landward side; (3) structural nosings; and (4) structural terraces. Most structural anomalies increase in size with depth. Stratigraphic mastery of accumulation occurs as a result of porosity variations and wedgeouts, especially in updip or downdip directions and in association with structural anomalies. Major accumulations are most common in the area of 30–50 per cent arenaceous material.

Approximately 4 billion barrels of oil and 10 trillion cubic feet of gas have been produced from a known minimum sedimentary volume of 265,000 cubic miles. Reserves in these same rocks are about 4 billion barrels of oil and 35 trillion cubic feet of gas, making a total of approximately 8 billion barrels of discovered oil and 45 trillion cubic feet of discovered gas. The amount of discovered oil per cubic mile (cubem) is 26,000 barrels, or 6000 less than the U. S. average of 32,000 barrels cited by L. G. Weeks in 1950. This is approximately one-half of Weeks' estimated potential total oil discovery averaging 50,000 barrels per cubic mile.

If hydrocarbons are present in similar quantities in the possible 250,000–500,000 cubic miles of offshore deposits in the Central Gulf region, estimated potential reserves in the area could be 8–25 billion barrels of oil and 40–125 trillion cubic feet of gas. Not all of this can presently be considered exploitable.

NOTES ON THE STRUCTURE OF THE VIRGINIA PIEDMONT

Wilbur A. Nelson
Dept. of Geology, University of Virginia, Charlottesville, Va.

Several Ordovician synclinal belts traverse the Piedmont of Virginia in a northeast-southwest direction. The first one on the west is the Everona limestone (Ordovician), which occupies a synclinal trough just east of Southwest Mountain. The second synclinal trough of Ordovician age is the Arvonia slate belt. The third synclinal trough of Ordovician age is occupied by the Occoquan slate belt and extends southwestward through Chancellorsville and toward Mineral, Virginia.

It is assumed that the Virgilina greenstone is the equivalent eastward extension of the Catoctin greenstone of Southwest Mountain at Charlottesville and that the Virgilina greenstone occupies a synclinal belt. It is also assumed that the aporhyolite mapped on the Virginia Geological Map of 1928 is a westward extension of the Swift Run formation which underlies the Catoctin in the Blue Ridge Mountains. This aporhyolite occurs west and east of the Virgilina greenstone which fits in with the synclinal interpretation given above. Just south of the Virginia line on the Roanoke River at Roanoke Rapids, North Carolina, drag folding in an intensely metamorphosed quartz chlorite gneiss (Wissahickon formation) indicates an almost north-south anticlinal fold in the vicinity of Roanoke Rapids.

MARINE FOSSILS IN SANDSTONES OF THE CHESTER SERIES OF WESTERN KENTUCKY

Edmund Nosow
Kentucky Geological Survey, Box 282, Hopkinsville, Ky.

Preliminary study of the Casky quadrangle in Christian County, Kentucky, indicates the fairly abundant occurrence of marine fossils in the Chester (Upper Mississippian) sandstones exposed. Previous work in western Kentucky has yielded only a few noted examples of marine fossils in the Cypress sandstone and mention of some in the Hardinsburg sandstone, although plant remains are

known to occur widely in Middle and Upper Chester beds. The sandstones generally exhibit cross-bedding, ripple marks, and other features suggesting marine deposition, and we should expect a greater faunal representation than has been reported.

Rapid transgressions and regressions of the sea causing a shifting strand line could account for the presence of land plants and marine fossils in the same formation, although some of the terrestrial fossils can occur as pseudoplankton in a marine environment.

Very fossiliferous zones in the Hardinsburg and Tar Springs sandstones are quite common in the Casky quadrangle, and indications are that certain faunal zones in these formations as well as in the Cypress sandstone may be fairly widespread.

In faulted areas the possibility of identifying some of the Chester sandstones is enhanced with the aid of these faunal assemblages.

ORIGIN OF A FLAT-LYING SILICEOUS LAYER IN THE GEORGIA PIEDMONT

Eldon J. Parizek and James F. Woodruff
University of Georgia, Athens, Ga.

Field work in the east-central Georgia Piedmont has focused attention on a fairly common layer composed primarily of fragmental quartz. In this area of widespread granitic bodies, magmatism as a genetic factor might be logically considered; however, field relations between the layer and adjoining materials contradict this supposition. This paper describes the layer and proposes that an assumed magmatic origin for the quartz layer is incorrect. Several hypotheses may better explain the observable features: (1) remnants of an old regolith, (2) silicification by ground water, (3) ionic diffusion, and (4) buried erosion surface. The authors tentatively conclude that none of the ideas explain the origin of the layer in all of its ramifications, but that a buried erosion surface may be genetically most significant.

GEOLOGY AND ORIGIN OF PEGMATITES IN VIRGINIA*

Arthur A. Pegau
Virginia Geological Survey, Charlottesville, Va.

Based on studies made during the past few years, the theories regarding geology of pegmatites may be classified into zonation, emplacement, and replacement.

The emphasis placed on the zoning or structure of pegmatites has been noticeably increased. This zonation is three dimensional and extends from the outside to the center of the pegmatite body: generally an outer zone, an intermediate zone, and a medial zone or core can be recognized.

The structural features in igneous rocks that control the emplacement of pegmatites include primary layering and other planar structures. The structural features in metamorphic rocks that control emplacement include bedding, foliation, and schistosity. Fracturing occurs in both kinds of rock.

The importance of replacement in pegmatite bodies has been recognized for many years, but in recent years replacement has been given much greater emphasis.

Recent theories regarding the origin of pegmatites do not differ greatly from those held for the past 20 years, despite the fact that the theories advanced for the origin of plutonic rocks have changed so materially in the past 10 years. In other words, most of the writers still consider that pegmatites are essentially of magmatic origin, rather than a product of metasomatic replacement.

SEDIMENTS OF PARTS OF MISSISSIPPI SOUND

Richard R. Priddy, Robert M. Crisler, Hugh Burford
Millsaps College, Jackson, Miss.

A second summer's work in the inshore waters of Mississippi Sound continued a study of bottoms suitable to oyster, shrimp, and fish. In 1952 most of the work was confined to microscopic studies with a view toward finding new inshore bottoms firm enough for oyster planting. Trial plantings have confirmed the value of this investigation.

* Presented with the permission of the State Geologist of Virginia

However, in 1953 the work was devoted to combined petrographic and chemical studies to establish the relationship of grain size and mineral composition to carbon, nitrogen, alumina, and iron content, and to density. Cores of the vital upper 15 inches were analyzed quantitatively on both weight and volume bases. In general, nitrogen and alumina content is highest at river mouths and in bayous, lower on oyster reefs, and very low on beaches. Most of the alumina is gelatinous material incorporated in the finer sediments which are also darkest by reason of iron sulphide rather than carbonaceous matter.

STRATIGRAPHIC PROBLEMS IN THE EASTERN GULF COASTAL PLAIN

E. H. Rainwater
Shell Oil Company, Jackson, Miss.

During the past 100 years many outstanding geologists and paleontologists have contributed to knowledge of the general stratigraphy of the Eastern Gulf Coastal Plain area, but many important stratigraphic problems remain. This paper points out some of these problems and possible methods of study. Increased exploration for oil and gas during the past several years has focused attention on the area and has made available much information on the buried formations.

The stratigraphic problems discussed are:

(1) The age, origin, and depositional conditions of the "Orange sand"-Citronelle formation. Despite the great amount of study on this blanket of heterogeneous material since Hilgard's time there is urgent need for paleontologic and stratigraphic study to establish age and depositional conditions of these deposits.

(2) Correlation of the thin Oligocene section in the Eastern Gulf Coastal Plain with the greatly expanded section in the subsurface of coastal Louisiana and Texas.

(3) The Wilcox (lower Eocene)-Midway (Paleocene) boundary. Position of this boundary in the subsurface section has never been determined. The problem is explained, and suggestions are made as to how detailed paleontologic and stratigraphic study can help solve the problem.

(4) Correlation and depositional history of the Lower Cretaceous formations. Thick deposits of this age are present in the subsurface in this area but in a facies different from that of the well-known Lower Cretaceous section in Texas. Zonation and correlation can be established only by study of well samples.

MOLLUSKS FROM THE MISSISSIPPI DELTA

Horace G. Richards
Academy of Natural Sciences and University of Pennsylvania, Philadelphia, Pa.

Through the courtesy of the Humble Oil and Refining Company, some mollusks from the Pleistocene and Post-Pleistocene section of several wells and bore holes in the Lower Mississippi Delta have been studied. Also, some specimens have been obtained from some mud lumps in the Gulf of Mexico off the mouth of the Mississippi River. While fewer species were noted in the mud-lump samples than in the wells, a similarity was noted between the fauna of the mud lump and that of the wells between 200 and 300 feet. Water of moderate depth (10 to 100 fathoms) is indicated. Many of the species are distributed from southern Florida to the West Indies, possibly indicating warmer water than that off the Delta today. Possibly the cooler waters of the Mississippi River entered the Gulf at a different location from today, thereby allowing the warmer waters of the Gulf to cover the present location of the lower Mississippi Delta.

COMPARISON BETWEEN ANATOLIAN RIVERS AND THE LOWER MISSISSIPPI

Richard J. Russell
Louisiana State University, Baton Rouge, La.

The Meander River, southwestern Anatolia, is a typical meandering river. Its channel widens, shoals, and straightens below tributaries bringing coarse sediments to its flood plain, but narrows,

deepens, and adopts a winding pattern through finer materials. The Meander and the Seyhan, near the Gulf of Iskenderun, have suffered numerous diversions. All Anatolian rivers exhibit the effects of alluvial drowning. Recent alluviation has converted lower parts of some tributary valleys into lake basins. Tectonic forces not only determine many main valley systems in Anatolia but also keep parts of the Meander and Ceyhan sharply confined along valley walls. Though the Seyhan and Ceyhan have built a compound delta and have many similarities, they exhibit a striking contrast in behavior arising from fault control of the position of the latter. The Lower Mississippi differs from Anatolian rivers most sharply in its ability to form clay plugs which confine it to definite meander belts, from which few major diversions have occurred. The Sakarya Delta, on the Black Sea, illustrates not only the way patterns of distributary streams originate in deltas such as that of the Mississippi but also how braided channels form in rivers generally.

TEST DRILLING ON THE EASTERN SHORE PENINSULA OF VIRGINIA

By Allen Sinnott and G. Chase Tibbitts, Jr.
U. S. Geological Survey, Charlottesville, Va.

As part of ground-water investigations in the Coastal Plain of Virginia in co-operation with the State Geological Survey, four test holes were drilled by the hydraulic-rotary method during the summer of 1953 on the Eastern Shore peninsula to depths of 470, 100, 450, and 451 feet. These wells lie along a 55-mile line from Capeville, near the south end of the peninsula, north-northeastward to Oak Hall, near the Maryland border. Samples were collected every 5 feet of depth, and Schlumberger electrical logs were run in each hole. Three of the wells penetrated more than 100 feet below the depth reached by any existing wells in their vicinities. Although age correlations have not been completed, preliminary work suggests that the three deeper wells have reached at least to the middle of the Miocene section. The electrical logs, which show good correlation among the wells, indicate also that ground water in the aquifers below 350 feet may be brackish.

GEOLOGIC AND HYDROLOGIC CONCEPTS OF THE WESTERN SECTION OF THE SOUTH CAROLINA COASTAL PLAIN

George E. Siple
U. S. Geological Survey, Box 5314, Columbia, S. C.

Co-operative ground-water investigations by the U. S. Geological Survey and the South Carolina Research, Planning and Development Board in parts of Aiken and Barnwell Counties, South Carolina, have revealed the presence of a hitherto unrecognized unit intermediate between the Tuscaloosa formation of Late Cretaceous age and the McBean formation of early Tertiary age. The unit is recognized only in the subsurface. Recognition was based on the lithology and structure of the unit and on the chemical characteristics of the circulating ground water. Areal geologic mapping revealed discordant contacts between Upper Cretaceous and Tertiary units and may support an assumption of post-Eocene subsidence in the Savannah River basin.

The geomorphology of the area is fairly typical of the inner margin of the Atlantic Coastal Plain where the unconsolidated sediments terminate against the crystalline rocks of the Piedmont. Where the Upper Cretaceous formations are capped by a Tertiary cover, topographic relief is accentuated, and there are numerous "sinks" or "bays". Several streams in the area have developed asymmetrical valleys, apparently substantiating Ferrel's law.

The most prolific aquifer in the area is sand and gravel of the Tuscaloosa formation. Transmissibility values ranging from 100,000 to 420,000 gallons per day per foot were calculated from pumping tests of wells obtaining water from this aquifer. A piezometric map of the aquifer indicates an area of discharge along the Savannah River below Augusta. The hydrologic data indicate that most of the recharge to the aquifer is effected by leakage through the confining Tertiary formations, and that the greater part of the discharge occurs in the outcrop area of the Tuscaloosa.

LOW-ANGLE OVERTHRUSTING IN THE CENTRAL CUMBERLAND PLATEAU, TENNESSEE

Richard G. Stearns
Tenn. Division of Geology, Nashville, Tenn.

A continuous series of thrust and cross faults is described and is named the Cumberland Plateau overthrust. This belt of faults is traced southwestward across the Cumberland Plateau of Tennessee from its junction with the Valley and Ridge thrusts near the north end of the Sequatchie Valley anticline.

Strata involved are briefly described insofar as they vary in competency and hence control the structural pattern.

Structural features of the area are described in detail. Data presented indicate that the faults bound a low-angle thrust sheet, and that associated anticlines are probably due to faulting at depth. This is demonstrated by the Big Peavine Mountain anticline which results from 3 miles of thrusting. The thrust forming this anticline outcrops 5 miles to the west as the Cumberland Plateau overthrust. The thrust extends eastward, arches over the Sequatchie Valley anticline, and has its roots in the Valley and Ridge Province.

The Cumberland Plateau overthrust is mechanically and regionally similar to the Pine Mountain overthrust to the north. It extends an unknown distance beyond 50 miles southwest of its junction with the Valley and Ridge province, perhaps as far south as Birmingham, Alabama (200 miles). These relationships support the vigorously debated sole-fault hypothesis of Southern Appalachian valley structure.

INFLUENCE OF GEOLOGY ON STREAM FLOW IN THE VICINITY OF THE FALL BELT IN EAST-CENTRAL GEORGIA

M. T. Thomson
District Engineer, Atlanta District, Surface Water Br., Water Resources Div., U. S. Geol. Survey, Atlanta, Ga.

Recent studies of stream flows of lesser streams in seven counties of East-Central Georgia show striking influence of the geology in three physiographic regions. The paper presents the minimum flows in the 1951 drought at 34 sites in million gallons per day per square mile of drainage area. Comparable values range from 0 to .03 in the Piedmont, 0 to .23 in the Fall Line Hills, and 0 to .005 in the Tifton Upland. Graphs show flow for various periods and the frequencies of drought flows at representative gaging stations. The underlying conditions, basic principles, and a method of using relationships among gaging stations for water supply needs are presented. Among all the factors that require consideration in the interpretation of streamflow records, geology is most important in the vicinity of the Fall Belt.

ABSTRACTS OF PAPERS SUBMITTED FOR THE MEETING IN BOULDER, COLORADO, MAY 7–8, 1954

ROCKY MOUNTAIN SECTION (GSA)

STRATIGRAPHY AND GEOLOGIC HISTORY OF PALEOCENE ROCKS IN THE VICINITY OF BISON BASIN, WYOMING

Wallace G. Bell
University of Wyoming, Laramie, Wyo.

Paleocene rocks are exposed in the Bison Basin area at the southeast end of the Wind River Mountains. These rocks consist of approximately 1000 feet of predominantly fine-textured, drab, sandy claystones which rest with 10–20-degree angular unconformity upon Upper Cretaceous strata. The lower part of the sequence is characterized by several lenticular, ridge-forming, fine-grained, locally glauconitic sandstones. The upper part contains several zones with lenticular conglomerates, the coarse fractions of which are made up predominantly of chert pebbles derived from the Permian Phosphoria formation and minor amounts of quartzitic fragments of Cloverly, Nugget, and Tensleep sandstones.

Fossil plants from the lower 750 feet are Paleocene in age; however, material collected from above this level could be latest Paleocene or earliest Eocene. A mammalian fauna of Tiffanian age (late Paleocene) has been collected from two horizons near the middle of the sequence.

The first major phase of the Laramide orogeny in this area occurred when a broad, easterly plunging fold developed at the southeast end of the incipient Wind River uplift. The Paleocene rocks of the Bison Basin area record the second phase which began when the earlier structural pattern was altered and deformation became localized in the area to the north now occupied by the Sweetwater arch. Paleocene sediments derived from the rising crests of folds to the north were carried southward and deposited across the truncated strata of the older fold.

The Paleocene rocks have been folded and faulted during subsequent stages of Laramide orogeny.

NEW OCCURRENCES OF DEVONIAN ROCKS IN NORTH-CENTRAL WYOMING

D. L. Blackstone, Jr. and Paul O. McGrew
University of Wyoming, Laramie, Wyo.

New occurrences of Devonian rocks in north-central Wyoming are established on fossil evidence. The fossiliferous Devonian sequence is well exposed in Cottonwood Canyon, T. 56 N., R. 93 W., Big Horn County, Wyoming. The basal unit is an ostracoderm-bearing channel deposit of red and gray siltstones; some coarse sandstone; and a basal conglomerate of Ordovician dolomite cobbles. The channel deposit has produced *Protaspis* cf. *dorfi*, *Cyrtaspis* cf. *ovatus*, and various arthrodires and crossopterygians of early Devonian age. Overlying the channel deposit is 250 feet of limestone, dolomite, and pale yellowish-green weathering siltstone with frosted quartz grains. A local black organic shale lens near the base yielded one specimen identified as *Bothriolepis* which occurs in middle and upper Devonian rocks. The uppermost unit is a 1-foot black, fissile to sandy shale yielding *Icriodus* sp., *Apatognathus* sp., and spores. The conodont genera indicate a middle and upper Devonian age.

A similar but nonfossiliferous red channel deposit exists in upper Dryhead Creek, Pryor Mountains, Montana. Lithologies similar to those above the Cottonwood Canyon channel deposit occur throughout the Pryor Mountains but have been previously mapped with the Madison limestone. Published stratigraphic sections and isopach maps of the Mississippian Madison limestone in this area have generally included the Devonian rocks and hence are in error.

The channel deposits are correlated with the Beartooth Butte formation, and the overlying rocks are correlated with the Jefferson limestone and the Three Forks shale of northwestern Wyoming.

STABILIZATION OF LANDSLIDES BY DRILLED HORIZONTAL DRAINS

Robert A. Bohman
U. S. Bureau of Public Roads, Denver Federal Center, Denver, Colo.

Landslides constitute a serious construction and maintenance problem to National Forest and Park highways in the Jackson Hole area, Wyoming. Slides that have been studied are a combination of slump and flow. Ground water is the most important single factor contributing to the movement of the slides.

The most economical and effective method of stabilization consists of partial dewatering of the material. This is accomplished by drilling into the landslide and casing the bore hole with perforated drain pipe. The bore hole is placed at a slight grade to permit free outflow of water. Individual drains installed by this method penetrate the slide materials as much as 250 feet and produce flows as high as 22,000 gallons per day.

Performance record data indicate that the method has been successful in retarding or stopping movement for the period under observation.

STRUCTURAL GEOLOGY OF THE ESTES PARK VALLEY, FRONT RANGE, COLORADO

Margaret Fuller Boos
2036 S. Columbine, Denver, Colo.

The Estes Park valley, a north-south elongated area of Precambrian rocks covering about 18 square miles east of Rocky Mountain National Park, Larimer County, Colorado, is both structural and erosional in origin.

The valley is in the northern part of the Longs Peak-St. Vrain batholith. The Estes Park beds of the Big Thompson series of metasedimentary formations and the Longs Peak (Silver Plume) and Mount Olympus granitic rocks constitute the bedrock. Intensely folded, crumpled, and faulted quartz gneiss, quartz-mica-sillimanite schist, injection gneiss, and knotenschiefer beds overlie the granites and are intruded by them.

The fairly flat, wide valley floor north of Lake Estes trends north-northeast and consists of folded and faulted schist, gneiss, and highly injected gneiss intruded by minor granite and pegmatite and beveled off by erosion. Granite mountains rise abruptly 800 to 1200 feet above the valley on the north, east, and west. The south half of the valley has moderate relief. Ridges and peaks of injection gneiss, up to 1500 feet thick, intruded by stocks and cupolas of granitic rock at the summit of the batholith, lie within the valley and around it.

A few large faults, hundreds of small ones, and innumerable joints affect the area. Earliest faults strike northeast and dip southeast. Those that strike northwest have nearly vertical dips and control minor drainage. North-south faults of small displacement along the eastern margin of the valley have thrust the injection gneiss and granite westward in many places.

A well-defined east-west fault and shear zone separates the complexly faulted and down-warped schist and gneiss-filled northern half of the valley from the granite-floored southern half which is also intricately faulted.

APPLICATION OF THE ALKALI-IRON-MAGNESIA TRIANGULAR DIAGRAM TO SEVERAL WESTERN TERTIARY VOLCANIC FIELDS

Byrl D. Carey, Jr.
University of Wyoming, Laramie, Wyo.

A modification of the alkali-iron-magnesia triangular diagram as utilized by Wager and Deer (1939), Walker and Poldervaart (1949), Tilley (1950), and Cornwall (1951) is applied to the chemical data of several volcanic fields in the Rocky Mountain and adjacent regions. The relative proportions of the weight percentages of $Na_2O + K_2O$, total iron as FeO, and MgO were determined and plotted so as to illustrate the differentiation trends in the Tertiary magmas of the Yellowstone Park, Sunlight district, Leucite Hills, and Rattlesnake Hills in Wyoming; the Rosita Hills, Cripple Creek dis-

trict, La Plata, and San Juan Mountains in Colorado; La Sal Mountains in Utah; and the San Francisco Mountains in Arizona.

The differentiation curves for all the volcanic areas except the Leucite Hills are in the vicinity of the curve obtained by plotting Daly's average basalt-andesite-dacite-rhyolite. The curve for the Leucite Hills is unique for the low FeO/MgO ratio (total iron as FeO).

The curves for the highly alkalic Cripple Creek and Rattlesnake Hills volcanic fields are almost identical with those obtained for the calc-alkalic Rosita Hills and San Francisco Mountains.

Stronger fractionation of the feldspars than of the ferromagnesian minerals, producing alkali enrichment throughout the crystallization period, is characteristic of all the volcanic fields discussed.

PATTERNED GROUND NEAR THE THULE AIR BASE

Roger B. Colton and C. D. Holmes
U. S. Geological Survey, Denver Federal Center, Denver, Colo.; University of Missouri, Columbia, Mo.

Surficial deposits in an area of 150 square miles near Thule Air Base, Greenland, were mapped during the summer of 1953. These deposits show the effects of intense frost action and the types of downslope movement prevalent in that latitude. Sorted net polygons, striped sorted polygons, solifluction lobes, stripes, and sheets, block-banked terraces, and frost-crack furrows cover much of the region.

Detailed studies of these features were made in certain favorable areas, with particular attention to their engineering-geology aspects such as problems of drainage and trafficability. Trenches through three sorted polygons yielded data on their internal structure. Development of frost features in this region is controlled by five main factors: (1) slope, (2) composition of the parent material, (3) drainage, (4) moisture content, and (5) depth of thaw.

In two areas, a total of 86 carefully surveyed control points were established in an attempt to measure the rate of movement of solifluction lobes. Results, however, must await a future resurvey.

SAND-DUNE DEVELOPMENT AND SEA-LEVEL CHANGES ON THE COAST OF NORTHERN OREGON

William S. Cooper
Boulder, Colo.

The important dune masses on the coast of northern Oregon are related to the mouths of bays and rivers. Each consisted originally of a massive parabola complex built by the southwest winds of winter. A rising and advancing sea has cut away large parts of these masses. In extreme cases only the northeast tip of the parabola complex and a narrow strip that constituted the inner margin of the system remain. Where direct connection with the beach has been maintained, the remnant of the parabola complex has been several times rejuvenated and is active today. Where the dune mass has been isolated by undercutting of the substratum it has become stabilized by forest and is wasting with extreme slowness at the seaward edge. It is suggested that the period of active destruction coincided with the eustatic rise of sea level during disappearance of the latest Wisconsin ice and that it came to an end at the time of the Thermal Maximum. Since then there have been alternations of rejuvenation and stabilization; during the last two or three centuries destructive forces have dominated.

CAMBRIAN STRATIGRAPHY AND FAUNAS OF THE WEST FLANK OF THE WIND RIVER MOUNTAINS, WYOMING

Charles Richard DeLand
Department of Geology, University of Wyoming, Laramie, Wyo.

Seven lithic units of Cambrian age are recognized in the Gros Ventre Mountains and in the exposures on the west flank of the Wind River Mountains as far south as Boulder, Wyoming; and five units are present on the Sweetwater River at the southern end of the Wind River Mountains.

The Flathead formation is present and of uniform character throughout the area studied.

In the northern Wind River Mountains the Gros Ventre formation consists of three lithic units:

the lower Wolsey shale, the Death Canyon limestone, and an unnamed upper shale. In the southern Wind River Mountains the Gros Ventre formation consists of an indivisible sequence of sandstones, limestones, and shales.

The Gallatin formation also comprises three subdivisions, which are from the base upward the Dunoir limestone, the Dry Creek shale, and the Sage limestone.

The succession of faunas is outlined.

ENGINEERING GEOLOGY OF THE KNIFE EDGE HIGHWAY RELOCATION AND TUNNEL SITE, MESA VERDE NATIONAL PARK, COLORADO

Ernest Dobrovolny, R. M. Lindvall, and Robert A. Bohman
U. S. Geological Survey, Denver Federal Center, Denver, Colo.; U. S. Geological Survey, Denver Federal Center, Denver, Colo.; U. S. Bureau of Public Roads, Denver Federal Center, Denver, Colo.

The proposed Knife Edge Highway relocation includes a 1400-foot tunnel to be driven near the contact between the Upper Cretaceous Mancos shale and the overlying Mesaverde group. Materials to be encountered in the tunnel are shale, sandy shale, and thin sandstone lenses, which will offer few problems in excavation, but which probably will require support as tunneling proceeds. The low dip of the strata, lack of channeling at the contact, and generally dry condition of the rocks indicate that drainage problems probably will be minor.

MAGNESIUM KAOLINITE FROM ELBRUS MINE, NORTH CAUCASUS

N. Efremov
1061 Intervale Ave., New York 59, N. Y.

Light-green flaky aggregates of magnesium kaolinite occur in contact with some ore (Zn, Pb)-bearing veins in the vicinity of Elbrus Mine and near the Jalankol River, North Caucasus. The mineral occurs also in Donets Basin. The chemical composition of this mineral from Elbrus Mine may be expressed as follows: $2MgO \cdot 2Al_2O_3 \cdot 3SiO_2 \cdot 4H_2O$. Spec. gr. 2.675. $N_x - 1.580$, $N_y - 1.576$, $N_z - 1.568$, $N_x - N_z = 0.012$. Optic sign +, $2V = +72$. The thermal-analysis curve of the mineral shows a great kaolinite endothermic reaction at 500°–600° and another small endothermic reaction at 830°–880°. The latter endothermic reaction passes to an intensive exothermic reaction at 900°. Judging by chemical composition, optical properties, thermal analysis, and x-ray data, this mineral resembles kaolinite and differs from chlorite, although it contains up to 15 per cent MgO. The formula of magnesium kaolinite $2Al_2O_3 \cdot 2MgO \cdot 3SiO_2 \cdot 4H_2O$ differs from that of kaolinite $2Al_2O_3 \cdot 4SiO_2 \cdot 4H_2O$ in the presence of $2Mg^{\cdot\cdot}$ corresponding to $Si^{\cdots\cdot}$ in kaolinite formula.

COEFFICIENT OF GEOCHEMICAL OXIDATION AS AN INDEX OF DEGREE OF SERPENTINIZATION OF ULTRABASIC ROCKS

N. Efremov
1061 Intervale Ave., New York, N. Y.

Coefficient of geochemical oxidation (K)—*i.e.*, the ratio between the negative mass (the sum of the atomic weights of negatively charged ions) and the positive mass (the sum of the atomic weights of positively charged ions)—is useful for characterizing some petrological processes. The rocks of the ultrabasic formation of the Caucasus show that the higher the coefficient of geochemical oxidation (K) of an ultrabasic rock, the more intense is its serpentinization; *e.g.*, dunite from the Zaguedan River—K = 0.82, nonserpentinized peridotite from Kestanty—K = 0.88, slightly serpentinized lherzolite from the Kefar River—K = 0.94, serpentinite from Mount Beden—K = 1.04, serpentinite from Mount Tkhach—K = 1.02. Consequently the hematite content in comparison to the magnetite content (*i.e.*, Fe_2O_3 in comparison to FeO) increases in highly serpentinized rocks. Over 70 chemical analyses of serpentinites from different massifs of the Caucasus and Transcaucasia show that K for these rocks (as well as for the upper part of lithosphere as a whole) is characterized by some equilibrium between the positive and the negative mass of ions.

POROUS-TUBE PIEZOMETER: AN INEXPENSIVE GROUND-WATER OBSERVATION DEVICE FOR THE GEOLOGIST

C. F. Erskine
U. S. Geological Survey, Denver Federal Center, Denver, Colo.

In connection with slope-stability studies along the banks of a large reservoir in South Dakota, the effect of the reservoir on the local water-table level had to be determined. To do this economically, engineers of the U. S. Bureau of Reclamation suggested using porous-tube piezometers, instruments used to study pore-water pressures.

The porous-tube piezometer is a short section of porous alundum tube placed in a small-diameter drill hole and connected to the ground surface by plastic tubing. Water enters through the porous tube and rises in the plastic tubing as it would in a standard observation well. The height to which water rises indicates the position of the water table if the saturated zone in which the tube is set is open to the atmosphere; the piezometric surface will be represented if the saturated zone is confined and the tube is sealed off from overlying materials.

There are three distinct advantages to using porous-tube piezometers instead of standard observation wells: (1) the small diameter of the system increases sensitivity by minimizing the change in water volume necessary to reflect a fluctuation of the water level; (2) porous tubes and plastic tubing are not subject to corrosion; (3) materials for porous-tube piezometers are several times cheaper than well points and iron-pipe casing.

Although some kind of power drill is most satisfactory for making the installation holes, a hand auger with extensions would be satisfactory for shallow holes in clay, silt, and other easily excavated materials.

ENGINEERING GEOLOGY OF THE RELOCATION OF STATE HIGHWAY 93 NEAR MARSHALL, COLORADO

L. M. Gard and Ernest Dobrovolny
U. S. Geological Survey, Denver Federal Center, Denver, Colo.

A geologic study of the site for a relocated segment of State highway 93 northwest of Denver, Colorado, was made by the Engineering Geology Branch of the U. S. Geological Survey as a demonstration of the applicability of geologic mapping to problems of highway construction. The relocated segment now under construction will provide access to the Rocky Flats plant of the Atomic Energy Commission.

The geologic conditions along 5 miles of the relocation route were examined. In most places apparently well-indurated sandstones of the Upper Cretaceous Fox Hills sandstone and Laramie formation could be excavated without using explosives. It was predicted that a 6-foot thick coal seam would crop out in the road bed in one proposed cut, and removal and replacement with more suitable subgrade material was recommended. Near Marshall the alignment crosses three northeast-trending normal faults which do not adversely affect the highway.

Clay minerals with expanding properties are present in some of the claystones of the Laramie, and special measures were taken to ensure that ground water would not seep into them and cause swelling beneath the road bed. Late Tertiary or early Quaternary gravels cap pediments along the mountain front. Ground water issuing from seeps and springs at the contact between these gravels and the underlying bedrock should be intercepted and removed from beneath the road bed.

MIGRATING DRAINAGE DIVIDE IN THE EAST TINTIC DISTRICT, UTAH

Harry D. Goode
U. S. Geological Survey, Denver, Colorado

Geomorphic studies in the East Tintic mining district have shown that in the vicinity of Silver Pass in the Eureka quadrangle, Utah, the main ridge of the East Tintic Mountains is migrating

westward. A landslide that probably occurred in early Wisconsin time—soils were used to date the event—and a very recent stream capture show that the divide has been migrating for a long time.

Water flowing eastward from Silver Pass drops about 1600 feet in 6 miles, whereas water flowing westward drops only about 1000 feet in the same distance; this difference in gradient is believed to have been the main factor in the migration of the divide.

NEW CLARENDONIAN FAUNA FROM WOLF CREEK, SOUTH DAKOTA

Morton Green
Museum of Geology, South Dakota School of Mines and Technology, Rapid City, S. D.

Scattered localities along the Wolf Creek drainage just east of Pine Ridge, Shannon County, South Dakota, have yielded a vertebrate fauna correlative with the Big Spring Canyon fauna 30 miles to the east.

The outcrops consist of tuffs, volcanic ash, sands, clays, and gravels considered part of the Ogallala Group. Most of the specimens come from a loosely consolidated white volcanic ash. There are no significant differences in specimens from above or below this ash, which is the most distinctive member.

The following genera are included in the Wolf Creek fauna: *Testudo, Soricid, Mylagaulus, Eucastor, Tomarctus,* cf. *Aelurodon,* ? *Pliocyon, Pliogale, Brachypsalis, Pseudaelurus, Neohipparion, Nannippus, Calippus, Pliohippus, Teleoceras, Procamelus, Pliauchenia,* and *Merycodus.* Not determinable are a rabbit resembling *Alilepus* and a geomyid resembling *Pliosaccomys.*

FAUNAS OF THE JOHN DAY FORMATION

Morton Green
Museum of Geology, South Dakota School of Mines and Technology, Rapid City, S. D.

Two faunas are represented in the John Day formation, each in a separate member. The lower member is late Oligocene in age (Whitneyan), its fauna represented by a single known vertebrate, *Archaeotherium.* This meager fauna is designated as the Cant Ranch local fauna equivalent to the Bridge Creek flora. The John Day faunal assemblage is found in the upper member of the formation and is early Miocene (Arikareean) in age. This fauna is the combined representation of vertebrates formerly known as the Middle John Day and Upper John Day faunas from beds heretofore called the middle and upper John Day. The John Day fauna is considered older than the faunas from the Gering and Monroe Creek formations of Nebraska because of the presence of several typically Oligorene genera, the more primitive nature of those genera that are also found in the Nebraska faunas, and the absence of several more advanced genera found only in the Nebraska faunas.

PETROLOGY OF A PORTION OF THE EASTERN FRONT OF THE BITTEROOT RANGE, MONTANA

S. L. Groff
Dept. of Geology, Montana State University, Missoula, Mont.

Existing papers concerning the origin of the gneissic east front of the Bitteroot Range, Montana, appear to be in disagreement. Waldemar Lindgren (1904) considered that the remarkably uniform slope was caused by a great normal fault and that the gneissic zone was the result of fault stresses. Langton (1935) accepted the fault concept and considered the gneiss to be formed from granitic rock older than the Idaho Batholith. Pardee (1950) cited geomorphic features indicating that such a fault may be present. C. P. Ross (1950) believed that the gneiss was a zone of granitized Beltian sediments and that the uniform slope was due to the doming effect of the Idaho Batholith.

Much of the gneissic rock of the mountain front west of Stevensville appears to be a mylonitic augen gneiss. Zircon of detrital origin is present, and quartz may be in excess of 90 per cent in the composition of some of the rock. A schist with foliation parallel to the gneiss and having sharp contacts with the gneiss is common in the frontal zone. Diopside is locally abundant near the west edge of this zone, and sillimanite is common in a contorted gneiss even farther westward.

In this area it is most probable that the frontal gneissic zone is composed of metasediments of Beltian age and that the cataclastic nature of the rock resulted from the intrusion of the Idaho batholith.

URANIFEROUS ASPHALTIC MATERIALS OF SOUTHWESTERN OKLAHOMA

James W. Hill*
U. S. Geological Survey, Denver, Colo.

Asphaltic deposits of southwestern Oklahoma were studied as part of the U. S. Geological Survey's reconnaissance for radioactive materials. The most uraniferous materials were small, black asphaltic pellets, which occur in bentonitic and arkosic red shale and sandstone of early Permian age. The relatively flat-lying Permian sedimentary rocks overlie steeply dipping petroliferous Ordovician limestone and dolomite and rounded ridges of Precambrian rhyolite porphyry on the north flank of the Wichita Mountains.

The asphaltic pellets are insoluble in organic reagents, are botryoidal in shape, and range in diameter from 1 mm. or less to 5 cm. Many of these pellets contain smaltite and uraninite and an unidentified uranium mineral. The uranium and total radioactivity are evenly distributed within a pellet.

The asphaltic pellets are largest and most numerous in permeable zones and along fracture openings and are associated with ground-water deposits. They are surrounded by bleached haloes in the enclosing rock and appear to be epigenetic. The internal structure of some pellets is similar to that of marcasite concretions. Their proximity to asphalt seeps suggests that the pellets may have been derived from that source. The presence of uraninite in the pellets, concentrations of rare earths in near-by asphalt, and similar concentrations in near-by hydrothermally altered granite suggest that some of the trace metals were derived indirectly from igneous sources.

CAUSES OF DIASTROPHISM

Donuil Hillis
4831 E. Harvard Lane, Denver, Colo.

Following the violent diastrophism that so strongly affected the Archeozoic strata, there has been sufficient time for isostatic adjustment and peneplanation to have brought about a state of equilibrium within the lithosphere.

Since this condition has not been achieved, a continuing source of energy is responsible for the deformation that has continued through the ages. Gravitational adjustments and erosion cause important deformation but are secondary agents that function only after a condition of unbalance develops through elevation of a portion of the lithosphere. This may be caused by ascending magma of batholithic proportions. Heat is the primary factor.

A diastrophic cycle is described, beginning with uplift, resulting in the formation of an adjoining geosyncline which, through weakening of the underlying lithosphere, itself becomes an area of uplift. Some crustal shortening occurs during the development of a geosyncline, but with the subsequent uplift that may convert it to a mountain range there is a tendency for elongation of the crust. This results in a thrust belt like that along the Idaho-Wyoming border. The north-south crustal shortening found in the Alps and Himalayas is related more to centrifugal force.

GEOLOGY OF THE CENTENNIAL REGION OF SOUTHWESTERN MONTANA

Fred S. Honkala
Geology Dept., Montana State University, Missoula, Mont.

The Centennial Region includes 500 square miles of southwestern Montana, mainly in Beaverhead County. The region, including the Centennial Valley, the western half of the Centennial Mountains, and the southern extensions of the Snowcrest and Gravelly ranges, was mapped in reconnaissance.

The Centennial Mountains are a southward-tilted fault block bounded on the north by the Cen-

*Subsequent to the preparation of this paper, James W. Hill was killed in an airplane crash while on duty with the U. S. Navy. The paper will be given by J. W. Mytton as a memorial to James W. Hill.

tennial fault and the downdropped Centennial Valley. The mountains are divided by a north-south normal (?) fault. The western half is chiefly folded Cretaceous sediments overlain by Tertiary volcanics. The eastern half is Paleozoic and Mesozoic rocks at its western end and Precambrian rocks at its eastern end. Glaciation has modified the north-facing mountain scarp.

North of the Centennial Valley is the Gravelly Range, an east-facing fault block (?) of Precambrian to Tertiary (?) rocks. The Metzel Creek anticline is located on the westward-dipping range slope, which flattens out into the Long Creek-Ruby River Basin. The basin is paralleled to the west by the Snowcrest Range, eroded from a large over turned fold in Paleozoic and Mesozoic rocks. At the south end of the range, the gently folded Cretaceous-Paleocene Beaverhead conglomerate unconformably overlies older folded Cretaceous rocks.

The chief mineral resource of potential economic importance in the Centennial Region is phosphate rock in the Permian Phosphoria formation. Oil possibilities of the region seem limited, but not impossible.

POLLEN AND SPORE FLORAS FROM THE LARAMIE FORMATION, JEFFERSON COUNTY, COLORADO

R. H. Howell, Jr.
1412 Kalmia Ave., Boulder, Colo.

Plant microfossils are abundant and well preserved in the coals and scanty and imperfectly preserved in the shales of the Laramie formation where it is exposed in Leyden Gulch south of Boulder, Colorado.

A statistical comparison of microfossils from several of the samples shows that the flora in sediments below a massive sandstone is distinctly different from that encountered above the sandstone in a total stratigraphic distance of about 125 feet. The pollen and spore assemblage is distinctly different from the present-day flora of the area in that there is a comparatively high percentage of fossil fern spores and cycad pollen. This suggests a much warmer, probably more moist climate at the time of deposition.

Many varieties of angiosperm pollen are present. The fact that these fossils have few positively identified counterparts in the present flora of the region is indicative of either evolutionary or ecologic change, or both, since Cretaceous time.

Coniferous pollen, a dominant element at present, is almost absent. The few grains observed could be explained as having been transported from an upland region at some distance from the site of deposition.

Plant microfossils have been successfully employed in other areas for correlation of sediments. Inasmuch as they are now known to exist in abundance in this area, further research may well prove their stratigraphic value in the Denver basin.

STRUCTURE OF THE AREA EAST OF BRUSH CREEK, EAGLE COUNTY, COLORADO

John F. Hubert
1040 Eleventh Street, Boulder, Colo.

The area east of Brush Creek lies northwest of the Sawatch Range, 30 miles east of Glenwood Springs, Colorado. Sedimentary formations are the Pennsylvanian Minturn shales and gypsum, Pennsylvanian-Permian Maroon red beds, Triassic Shinarump conglomerate and Chinle red beds, Jurassic Entrada sandstone and Morrison limestones and varicolored shales, and Cretaceous Dakota (?) sandstone and Benton shale. Unconformities occur at the base of the Shinarump, Entrada, and Dakota (?) formations.

Following late Cretaceous deposition strong northwest-southeast compressional forces associated with Laramide deformation of the Sawatch Range produced a major northeast-trending syncline and a system of northeast-trending thrust faults. Differential uplift between the White River region and the Sawatch Range, possibly in post-Wasatch (early Eocene) time, resulted in a set of northwest-trending vertical faults that truncate the earlier thrust faults. A stock was subsequently intruded into zones of weakness formed by intersection of the two fault systems, and a tonalite porphyry body

rose along a fault plane and intruded the Dakota (?) sandstone as a thick sill. Hydrothermal solutions, localized by a thrust fault on Horse Mountain, deposited copper and silver mineralization in the Entrada sandstone. Early Miocene lava flowed out on a surface of low relief truncating tilted sediments. Later the lava slumped or was slightly folded. Two stages of Pleistocene glaciation left erosional and depositional features on Porphyry Mountain.

SELENIUM IN SULFIDE ORES

E. P. Kaiser*
U. S. Geological Survey, Denver, Colo.

As part of the work of the U. S. Geological Survey on minor elements in mineral raw materials and mill and smelter products, more than 50 samples of sulfide ores and their products have been analyzed, by spectrographic methods for about 15 of the minor elements and by chemical analysis for selenium. The analytical method for selenium is sensitive down to concentrations of about 0.0002 per cent (2 ppm). Base-metal concentrates contain as much as 700 ppm selenium.

Mill concentrates relatively high in selenium generally are also high in bismuth, cobalt, tin, and zirconium. Minerals containing selenium are almost never recognized in the deposits. The available evidence indicates that selenium, like many other minor elements, is relatively more abundant in the sulfide deposits of certain geographic areas. One such selenium province is the mountainous region of central Arizona. A clue to selenium provinces may be gleaned from analyses of smelter-flue dusts.

There is no apparent connection between the concentration of selenium in epigenetic ore deposits and its concentration in sedimentary rocks, such as the well-known selenium-bearing shales of Cretaceous age in the Great Plains area, but the data are extremely scanty. These selenium-bearing shales are widespread and probably received their selenium from Cretaceous volcanic materials. Some recent volcanic materials, especially sulfur, are notably rich in selenium.

MONOCLINES OF THE COLORADO PLATEAU

Vincent C. Kelley
University of New Mexico, Albuquerque, N. M.

Monoclines on the Plateau have an aggregate linear extent of nearly 2500 miles. The features considered include true monoclines, steep limbs of asymmetrical or tilted anticlines, steep flexes along faults, and, locally, parts of noses along plunging folds. Attitudes of the monoclinal flexes range from about 10° to steeply overturned. The greatest uninterrupted monocline is nearly 250 miles in length, and it displays the complete range of fold intensity.

Sinuous configurations of trend are characteristic of the long monoclines. Several types of winding trends may be distinguished. The relationships of the various kinds of monoclines to one another and to the adjoining or incorporating uplifts and basins are discussed.

The monoclines may be considered as the essence of the Plateau structure. They are the crux of a tectonic analysis. Their origin is discussed.

GEOLOGY OF A PORTION OF THE WHITE RIVER BADLANDS, PENNINGTON COUNTY, SOUTH DAKOTA

Roy C. Kepferle
South Dakota School of Mines, Rapid City, S. D.

A change in lithology, color, and topographic expression marks the conformable contact between the Chadron formation and the overlying Brule formation where these Oligocene sediments are exposed in the northern halves of the Imlay and Sheep Mountain Table quadrangles. This area was mapped in 1953 on a topographic base published by the United States Geological Survey, supplemented by air photos. Structure contours on the datum plane of the Chadron-Brule contact indicate a dip of 30 to 40 feet per mile to the east-southeast.

Samples of swelling claystone characteristic of the Chadron formation were tested for properties

* With technical assistance of H. W. Lakin.

essential to commercial bentonite. The results indicate that the grit content is too high and the viscosity too low for profitable processing.

Of special interest are the fractures of the area. Some are oriented at random, are seldom more than an inch wide, and are generally filled with chemically precipitated chalcedony, gypsum, or calcite. Others are oriented more orderly, are several inches wide, and generally are filled with limy siltstone and sandstone, but may also contain the chemical precipitates mentioned. The fractures oriented at random suggest an origin by desiccation of the surrounding claystones and siltstones; the orderly oriented fractures may be structurally controlled.

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In north-central North Dakota, well-oriented linear glacial ridges deposited by ice of the Mankato substage of Wisconsin age are 3 to 30 feet high and a few hundred feet to 15 miles long, and trend southeast in a conspicuous parallel pattern. They consist of both till and stratified drift. Indistinct linear grooves in the surrounding ground-moraine plain parallel the ridges. Chains of elongated undrained depressions and of very low washboard moraines form a series of lobate lineations transverse to the ridges and grooves.

The linear ridges were formerly interpreted by Lemke, Jensen, and Smith (1951) to be crevasse fillings deposited in the glacial ice. Subsequent studies in surrounding areas with the aid of aerial photos, a better knowledge of the internal structure of the ridges based on drilling in the deposits, and recent literature describing somewhat similar features have led the author to abandon his previous interpretation. He now interprets the ridges as a special type of drumlinoidal feature deposited by the advancing ice sheet parallel to the direction of advance. It is still not clear, though, how such a feature could be composed of large amounts of stratified drift.

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The northern part of the Sangre de Cristo Mountains of Colorado is bounded on the west by a steep normal fault whose vertical displacement may be measured in thousands of feet.

Paleozoic sediments as far south as Orient dip steeply east and probably represent the east flank of a large anticlinorium whose axis nearly parallels the range. Sediments cross the crest of the range at Hayden Pass.

In many places the lower Paleozoic strata are repeated by high-angle reverse faults which relieved compressive stresses acting in a southwesterly direction. Strong north-northwest reverse faults north of Orient probably follow pre-existing zones of weakness in the basement complex. It is suggested that where these faults cut sediments they were localized between the thick, massive Permo-Pennsylvanian sandstones and the Precambrian basement rocks because the lower Paleozoic strata presented a zone of relative weakness. Possibly similar structures exist in the upper Paleozoic rocks but have escaped detection because of lack of good horizon markers.

The high-angle reverse faults are interpreted as Laramide structures. The normal fault west of the range was probably active intermittently from Miocene to Pleistocene time.

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The fauna includes *Tomarctus, Aelurodon, Pliocyon, Merychippus, Calippus, Nannippus, Neohipparion, Pliohippus, Tapirus, Teleoceras, Peraceras, Ustatochoerus, Prosthennops, Procamelus, Pliauchenia,* and *Merycodus.*

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Garnet Ridge, about 35 miles northeast of Kayenta, Arizona, is a low, oval butte, 3 miles wide and 8 miles long, composed of Upper Jurassic rocks. The ridge is perforated by four serpentine pipes. Three of the pipes form a cluster, 1500 by 4000 feet, around which country rocks are downwarped in a syncline with a length of 2 miles and a closure of 160 feet. Two kinds of material fill the pipes: (1) pulverized serpentine rubble containing pebbles and boulders of Paleozoic age and crystalline rocks derived from below, and (2) large blocks of Jurassic and Cretaceous rocks derived from above. Pipe formation and serpentine intrusion were probably contemporaneous and date back to Tertiary time when rocks of Cretaceous age covered the area.

The serpentine rubble consists largely of serpentine with less abundant calcite and chlorite, and minor amounts of olivine, chrome-diopside, biotite, pyrope, and montmorillonite. Xenoliths in the serpentine are not visibly altered, and wall-rock alteration is local and weak.

Serpentine rubble occurs also as surficial deposits that cap a row of knobs extending half a mile from a pipe at the crest of Garnet Ridge. Lack of feeder dikes and the presence of locally derived talus under the rubble argue against intrusive emplacement. The knobs are interpreted as the trace of a former valley into which serpentine rubble was extruded from the pipe—but much later than the initial intrusions—after 1000 feet or more of erosion.

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Missouri into porous sandstone and joints in the Kootenai formation. Recent detailed geologic mapping in the vicinity of Great Falls has produced evidence that refutes both hypotheses.

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The ore body studied is lenticular, essentially horizontal, and has an area of 30,000 square feet. It is approximately 50 feet below the surface and ranges in thickness from 17 feet near the center to a feather edge at the margins.

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Eight of eleven symmetry vectors determined from this study trend roughly eastward, parallel to the trend of known mineralized ground in the area of the Legin group of mines.

Additional studies of the distribution of elements within uranium-vanadium deposits of the Colorado Plateau type may show that the trend of mineralized ground in a district can be determined by statistical methods from fewer data than are needed for determining regional trends by established methods.

GEOLOGY OF SPRING CREEK PARK, GUNNISON COUNTY, COLORADO

Fred F. Meissner
Colorado School of Mines, Golden, Colo.

Spring Creek Park, a small, flat, unforested valley flanked by mountain slopes, is situated on the western edge of a northwesterly plunging synclinorium bounded by anticlinal elements of the Elk Mountains to the north, of the Sawatch Range to the east, and of the Cement Mountain uplift to the southwest.

Sedimentary beds overlying Precambrian Silver Plume granite include Cambrian Sawatch quartzite; Ordovician Manitou dolomite, Harding sandstone, and Fremont limestone; Devonian Chaffee formation; Mississippian Leadville limestone; and Pennsylvanian Belden shale and Gothic formation. Erosion has removed Mesozoic rocks. Late Cretaceous or early Tertiary igneous rocks intrude the sedimentary sequence forming dikes, sills, and a small stock. Rock types represented include rhyolite-quartz latite porphyry containing sanidine, quartz latite porphyry, andesite porphyry, and fine-grained diaschistic quartz monzonite. A Pleistocene outwash fan extends along Spring Creek valley from a glacial moraine developed north of the Park.

Major Laramide structure is reflected by a northwesterly plunging anticlinal nose extending from

the Cement Mountain uplift and by a centrally located major thrust fault which dips northeasterly and strikes northwesterly. Numerous minor folds and faults are also present. The tectonic pattern indicates southwesterly compression from the Elk Mountains toward the Cement Mountain uplift.

The area embraces part of the Spring Creek mining district. The Doctor Mine, the only major property within the district, has produced major quantities of oxidized lead and zinc ore from a replaced breccia zone in the Leadville limestone adjacent to the major thrust fault.

ESTIMATION OF LOW-RELIEF SLOPES IN ARID REGIONS FROM AIR PHOTOS

Richard Merriam
Geology Department, University of Southern California, Los Angeles 7, Calif.

The slopes of areas having relief too low to be apparent when observed in stereo pairs of aerial photographs may be estimated by study of the braiding patterns of washes and alluvial fan distributaries. The ratio of length to width of rhomb-shaped "islands" between washes is roughly proportional to the gradient. Complicating factors are: median diameter and permeability of alluvium, size of watershed, and vegetation. Control by a slope of known gradient in the same or similar area improves the results which may otherwise be largely relative. Scales between 1:30,000 and 1:10,000 are best; stereo pairs are not necessary.

SEQUENCE OF ALLUVIATION ALONG THE LOUP RIVERS, VALLEY COUNTY, NEBRASKA

Robert D. Miller and Glenn R. Scott
U. S. Geological Survey, Denver Federal Center, Denver, Colo.

Alluviation along the Loup Rivers in Valley County, Nebraska, consists of a series of alluvial silt beds upon which are developed six interstadial soils. The six soils are identified as Yarmouth, Brady (of authors), Cary-Mankato, Mankato, early Recent, and late Recent. No deposits of Illinoian age are represented in the alluvial sequence, and in at least one place the Brady soil is superposed on soil of Yarmouth age. The latter is developed on the Sappa formation, which overlies the Grand Island formation. Post-Yarmouth erosion removed the Sappa formation and part of the Grand Island formation in most places. The lack of Sangamon weathering on uneroded remnants of the soil of Yarmouth age is considered the result of a wet, poorly drained environment. A large collection of mollusks obtained from this soil confirms earlier conclusions, based on stratigraphic evidence, as to the age of the soil.

Deposition of alluvium during the glacial substages of Wisconsin time, and soil formation during the interglacial substages, continued uninterrupted by erosion until after development of the early Recent soil. The Wisconsin deposits were dissected to a depth below the Brady soil in places, and the gully was filled with Recent alluvium. The Recent fill terrace lies 15 feet lower than the top of the late Wisconsin terrace. Cutting during late Recent time and the subsequent filling of the gullies by late Recent alluvium produced another terrace 11 feet below the older terrace. The modern gully was cut during the last century.

PRECAMBRIAN STRUCTURES IN THE VICINITY OF IDAHO SPRINGS, FRONT RANGE, COLORADO

R. H. Moench, J. E. Harrison, P. K. Sims
U. S. Geological Survey, Denver, Colo.

Detailed geologic mapping in the vicinity of Idaho Springs, Colorado, has shown that the metamorphic rocks there were subjected to two periods of folding in the Precambrian. In a single exposure all linear elements of both fold systems may be present.

In the older fold system: (1) the folds in some areas are broad and open with axes trending approximately N. 30° E. and with axial planes of minor closed folds converging upward on the anticlines; (2) in other areas major folds are closed, with axes trending N. 30° E. and with axial planes dipping northwest; (3) the axes of open folds are continuous with axes of closed folds; (4) linear

structures have an average trend of N. 30° E. (*b*) and N. 60° W. (*a*); and (5) plastic deformation was accompanied by strong recrystallization.

The younger fold system is superimposed on the older and is most strongly developed where the earlier folds are closed. In this younger system: (1) folds are asymmetric with axes that trend N. 60° E., the northwest limbs of the anticlines dipping steeply northwest and their southeast limbs dipping gently southeast; (2) local closed folds are superimposed on closed folds of the first system; (3) the present attitude of pre-existing foliation delineates the plunge of the younger folds; (4) linear structures trend N. 60° E. (probably *b*) and N. 20° W. (probably *a*); and (5) cataclastic texture has been recrystallized, but the recrystallization was weaker than in the first folding.

TERTIARY STRUCTURE, FAUNA, AND LITHOLOGY IN THE UPPER SARATOGA VALLEY-BIG CREEK PARK AREA, WYOMING AND COLORADO

John de la Montagne
Colorado School of Mines, Golden, Colo.

Vertebrate fossils in the southern part of Saratoga Valley indicate the presence of two formations, the North Park, containing late Barstovian (latest Miocene to earliest Pliocene) forms, and a possible equivalent of the Browns Park formation containing Hemingfordian (middle Miocene) forms. Both sequences are faulted.

Channel fills composed predominantly of rounded volcanic cobbles and transported by the ancestral North Platte are confined to the middle part of Saratoga Valley. These channel fills intertongue westward into tuffs, tuffaceous sandstones, siltstones, and conglomerates along the valley flank, wedging out before reaching the Park Range foothills. Unusual conglomerates in the latter "flank sequence" consist of angular Precambrian fragments up to 10 feet in longest dimension plastered with pre-existing Tertiary ash clays and sandstones in a matrix of calcium carbonate and devitrified volcanic ash.

Along Six Mile Creek the channel beds contain mammalian remains identified by McGrew as *Merycodus*, advanced *Merychippus*, a camel, and a rhinoceros. Contemporary genera including *Ustatochoerus*, *Merycodus*, and *Eucastor* ? are contained in downfaulted beds of the flank sequence immediately east and west of the foothill ridges. This assemblage is probably latest Barstovian, but earliest Clarendonian is not precluded.

Hemingfordian oreodont remains occur in faulted beds of Big Creek Park, also west of the foothill margins. These beds are lithologically indistinguishable from later sediments in and near Saratoga Valley proper and may be correlative with the Browns Park formation in lower Saratoga Valley.

Faunal dating of faults in Saratoga Valley indicates that other faults in the region may be post-Barstovian.

PERMIAN-JURASSIC FACIES, SOUTHERN FRONT RANGE OF COLORADO

Lawrence Ogden
Colorado School of Mines, Golden, Colo.

Beds of sedimentary gypsum with a total maximum thickness of 150 feet are found in the sediments flanking the south end of the Front Range of Colorado. The gypsum occurs in both the Lykins formation (Permo-Triassic age) and the Ralston formation (Upper Jurassic age). In an east-west distance of 25 miles the gypsum interfingers with a shale-marlstone facies to the east and a sandstone-arkosic conglomerate facies to the west. Equivalency of these three facies is proved by the presence of continuous marker beds at both top and bottom of the sequence and by the interfingering of the three lithologies. On the basis of this correlation sediments exposed near Canon City, Colorado, previously thought to be included in the lower part of the Morrison formation, are now considered to be facies of the Lykins formation. Within the area discussed the geologic history of Permian through Late Jurassic times involves simultaneous deposition of fine clastics and carbonates, gypsum, and coarse clastics in a single sedimentary basin. The coarse material deposited in the western part

of the area was probably derived from a source in the vicinity of the present Wet Mountains of Colorado. The source area subsided before Morrison (Upper Jurassic) time as both Morrison and Dakota sediments rest unconformably on the Precambrian rocks in the Wet Mountains.

TETRADYMITE IN SUMMIT COUNTY, COLORADO

Ben H. Parker, Jr.
P. O. Box 508, Golden, Colo.

Significant megascopic quantities of tetradymite (Bi_2 (Te, $S)_3$) have been identified in specimens from the upper portions of the Gold Crest vein, in Sec. 29, T. 7. S., R. 78 W., Summit County, Colorado. Positive identification has been made by means of chemical and x-ray analyses. The tetradymite is associated with quartz, pyrite, gold, and minor chlalcopyrite. The paragenetic relations of this tetradymite and of the "bismuth period" group of minerals described by Behre (1953) in the west slope of the Mosquito Range appear similar.

PARAGENESIS AND AGE OF THE URANIUM MINERALS IN THE COPPER KING MINE, LARIMER COUNTY, COLORADO*

George Phair and Paul K. Sims
U. S. Geological Survey, Denver Federal Center, Denver, Colo.

Ore deposition at the Copper King mine, Larimer County, Colorado, took place at three widely spaced periods and formed (1) an early high-temperature assemblage of magnetite, marmatite, pyrrhotite, pyrite, and chalcopyrite; (2) a later assemblage of black uranium minerals with siderite, silica, iron oxides, and sparse sulfides; and (3) supergene uranium minerals.

The high-temperature deposit is in metasediments enclosed by a younger granite. The richest sulfide ore, a heavy boxwork, selectively replaced amphibole skarn. Age determinations on ore magnetite by the helium method of Hurley and on monazite from associated pegmatites by the Th/Pb method indicate that both minerals formed in the late Precambrian.

The uranium was introduced into fractures in the earlier skarn ore and granite during or after a period of faulting and brecciation. It occurs in three black phases, which can be distinguished by X-ray diffraction: (1) Pitchblende, with the normal face-centered cubic diffraction pattern and high density, forms high-grade veinlets in the boxwork ore. It also occurs as disseminations and veinlets in the main breccia zone, where it is minutely intergrown with siderite and with (2) a new black uranium mineral giving a tetragonal diffraction pattern. This new mineral resembles the pitchblende in chemical composition but has a lower density. (3) Probable supergene UO_3-rich pitchblende amorphous to X-rays coats leached cavities in the boxwork sulfides. Good Pb/U ratio determinations on three samples of hard unaltered pitchblende from the main breccia zone indicate an early Tertiary age (62 $\pm$ 10 million years).

MOUNT SOPRIS STOCK, PITKIN COUNTY, COLORADO

H. D. Pilkington and C. L. Pillmore
Department of Geology, University of Colorado, Boulder, Colo.

The stock exposed on Mount Sopris is one of several Tertiary igneous bodies exposed along the crest of the Elk Mountains in central Colorado. The stock consists of granodiorite and was forcibly intruded into folded and faulted Permo-Pennsylvanian sediments. Extensive contact breccias, numerous inclusions, and notable variations in mineralogy suggest incorporation of considerable volumes of country rock by piecemeal stoping. Thermal metamorphism of the surrounding sediments resulted in formation of hornfels and was accompanied by considerable hydrothermal activity. Sericitization of the feldspars, intense albitization, and introduction of quartz to form graphic and myrmekitic intergrowths are deuteric-stage phenomena. Late hydrothermal activity produced several

* Published by permission of the Director, U. S. Geological Survey, Washington, D. C.

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Colorado School of Mines, Golden, Colo.

Spring Creek Park, a small, flat, unforested valley flanked by mountain slopes, is situated on the western edge of a northwesterly plunging synclinorium bounded by anticlinal elements of the Elk Mountains to the north, of the Sawatch Range to the east, and of the Cement Mountain uplift to the southwest.

Sedimentary beds overlying Precambrian Silver Plume granite include Cambrian Sawatch quartzite; Ordovician Manitou dolomite, Harding sandstone, and Fremont limestone; Devonian Chaffee formation; Mississippian Leadville limestone; and Pennsylvanian Belden shale and Gothic formation. Erosion has removed Mesozoic rocks. Late Cretaceous or early Tertiary igneous rocks intrude the sedimentary sequence forming dikes, sills, and a small stock. Rock types represented include rhyolite-quartz latite porphyry containing sanidine, quartz latite porphyry, andesite porphyry, and fine-grained diaschistic quartz monzonite. A Pleistocene outwash fan extends along Spring Creek valley from a glacial moraine developed north of the Park.

Major Laramide structure is reflected by a northwesterly plunging anticlinal nose extending from

the Cement Mountain uplift and by a centrally located major thrust fault which dips northeasterly and strikes northwesterly. Numerous minor folds and faults are also present. The tectonic pattern indicates southwesterly compression from the Elk Mountains toward the Cement Mountain uplift.

The area embraces part of the Spring Creek mining district. The Doctor Mine, the only major property within the district, has produced major quantities of oxidized lead and zinc ore from a replaced breccia zone in the Leadville limestone adjacent to the major thrust fault.

ESTIMATION OF LOW-RELIEF SLOPES IN ARID REGIONS FROM AIR PHOTOS

Richard Merriam
Geology Department, University of Southern California, Los Angeles 7, Calif.

The slopes of areas having relief too low to be apparent when observed in stereo pairs of aerial photographs may be estimated by study of the braiding patterns of washes and alluvial fan distributaries. The ratio of length to width of rhomb-shaped "islands" between washes is roughly proportional to the gradient. Complicating factors are: median diameter and permeability of alluvium, size of watershed, and vegetation. Control by a slope of known gradient in the same or similar area improves the results which may otherwise be largely relative. Scales between 1:30,000 and 1:10,000 are best; stereo pairs are not necessary.

SEQUENCE OF ALLUVIATION ALONG THE LOUP RIVERS, VALLEY COUNTY, NEBRASKA

Robert D. Miller and Glenn R. Scott
U. S. Geological Survey, Denver Federal Center, Denver, Colo.

Alluviation along the Loup Rivers in Valley County, Nebraska, consists of a series of alluvial silt beds upon which are developed six interstadial soils. The six soils are identified as Yarmouth, Brady (of authors), Cary-Mankato, Mankato, early Recent, and late Recent. No deposits of Illinoian age are represented in the alluvial sequence, and in at least one place the Brady soil is superposed on soil of Yarmouth age. The latter is developed on the Sappa formation, which overlies the Grand Island formation. Post-Yarmouth erosion removed the Sappa formation and part of the Grand Island formation in most places. The lack of Sangamon weathering on uneroded remnants of the soil of Yarmouth age is considered the result of a wet, poorly drained environment. A large collection of mollusks obtained from this soil confirms earlier conclusions, based on stratigraphic evidence, as to the age of the soil.

Deposition of alluvium during the glacial substages of Wisconsin time, and soil formation during the interglacial substages, continued uninterrupted by erosion until after development of the early Recent soil. The Wisconsin deposits were dissected to a depth below the Brady soil in places, and the gully was filled with Recent alluvium. The Recent fill terrace lies 15 feet lower than the top of the late Wisconsin terrace. Cutting during late Recent time and the subsequent filling of the gullies by late Recent alluvium produced another terrace 11 feet below the older terrace. The modern gully was cut during the last century.

PRECAMBRIAN STRUCTURES IN THE VICINITY OF IDAHO SPRINGS, FRONT RANGE, COLORADO

R. H. Moench, J. E. Harrison, P. K. Sims
U. S. Geological Survey, Denver, Colo.

Detailed geologic mapping in the vicinity of Idaho Springs, Colorado, has shown that the metamorphic rocks there were subjected to two periods of folding in the Precambrian. In a single exposure all linear elements of both fold systems may be present.

In the older fold system: (1) the folds in some areas are broad and open with axes trending approximately N. 30° E. and with axial planes dipping minor closed folds converging upward on the anticlines; (2) in other areas major folds are closed, with axes trending N. 30° E. and with axial planes dipping northwest; (3) the axes of open folds are continuous with axes of closed folds; (4) linear

structures have an average trend of N. 30° E. (*b*) and N. 60° W. (*a*); and (5) plastic deformation was accompanied by strong recrystallization.

The younger fold system is superimposed on the older and is most strongly developed where the earlier folds are closed. In this younger system: (1) folds are asymmetric with axes that trend N. 60° E., the northwest limbs of the anticlines dipping steeply northwest and their southeast limbs dipping gently southeast; (2) local closed folds are superimposed on closed folds of the first system; (3) the present attitude of pre-existing foliation delineates the plunge of the younger folds; (4) linear structures trend N. 60° E. (probably *b*) and N. 20° W. (probably *a*); and (5) cataclastic texture has been recrystallized, but the recrystallization was weaker than in the first folding.

TERTIARY STRUCTURE, FAUNA, AND LITHOLOGY IN THE UPPER SARATOGA VALLEY-BIG CREEK PARK AREA, WYOMING AND COLORADO

John de la Montagne
Colorado School of Mines, Golden, Colo.

Vertebrate fossils in the southern part of Saratoga Valley indicate the presence of two formations, the North Park, containing late Barstovian (latest Miocene to earliest Pliocene) forms, and a possible equivalent of the Browns Park formation containing Hemingfordian (middle Miocene) forms. Both sequences are faulted.

Channel fills composed predominantly of rounded volcanic cobbles and transported by the ancestral North Platte are confined to the middle part of Saratoga Valley. These channel fills intertongue westward into tuffs, tuffaceous sandstones, siltstones, and conglomerates along the valley flank, wedging out before reaching the Park Range foothills. Unusual conglomerates in the latter "flank sequence" consist of angular Precambrian fragments up to 10 feet in longest dimension plastered with pre-existing Tertiary ash clays and sandstones in a matrix of calcium carbonate and devitrified volcanic ash.

Along Six Mile Creek the channel beds contain mammalian remains identified by McGrew as *Merycodus*, advanced *Merychippus*, a camel, and a rhinoceros. Contemporary genera including *Ustatochoerus*, *Merycodus*, and *Eucastor* ? are contained in downfaulted beds of the flank sequence immediately east and west of the foothill ridges. This assemblage is probably latest Barstovian, but earliest Clarendonian is not precluded.

Hemingfordian oreodont remains occur in faulted beds of Big Creek Park, also west of the foothill margins. These beds are lithologically indistinguishable from later sediments in and near Saratoga Valley proper and may be correlative with the Browns Park formation in lower Saratoga Valley.

Faunal dating of faults in Saratoga Valley indicates that other faults in the region may be post-Barstovian.

PERMIAN-JURASSIC FACIES, SOUTHERN FRONT RANGE OF COLORADO

Lawrence Ogden
Colorado School of Mines, Golden, Colo.

Beds of sedimentary gypsum with a total maximum thickness of 150 feet are found in the sediments flanking the south end of the Front Range of Colorado. The gypsum occurs in both the Lykins formation (Permo-Triassic age) and the Ralston formation (Upper Jurassic age). In an east-west distance of 25 miles the gypsum interfingers with a shale-marlstone facies to the east and a sandstone-arkosic conglomerate facies to the west. Equivalency of these three facies is proved by the presence of continuous marker beds at both top and bottom of the sequence and by the interfingering of the three lithologies. On the basis of this correlation sediments exposed near Canon City, Colorado, previously thought to be included in the lower part of the Morrison formation, are now considered to be facies of the Lykins formation. Within the area discussed the geologic history of Permian through Late Jurassic times involves simultaneous deposition of fine clastics and carbonates, gypsum, and coarse clastics in a single sedimentary basin. The coarse material deposited in the western part

of the area was probably derived from a source in the vicinity of the present Wet Mountains of Colorado. The source area subsided before Morrison (Upper Jurassic) time as both Morrison and Dakota sediments rest unconformably on the Precambrian rocks in the Wet Mountains.

TETRADYMITE IN SUMMIT COUNTY, COLORADO

Ben H. Parker, Jr.
P. O. Box 508, Golden, Colo.

Significant megascopic quantities of tetradymite (Bi_2 (Te, S)$_3$) have been identified in specimens from the upper portions of the Gold Crest vein, in Sec. 29, T. 7. S., R. 78 W., Summit County, Colorado. Positive identification has been made by means of chemical and x-ray analyses. The tetradymite is associated with quartz, pyrite, gold, and minor chlalcopyrite. The paragenetic relations of this tetradymite and of the "bismuth period" group of minerals described by Behre (1953) in the west slope of the Mosquito Range appear similar.

PARAGENESIS AND AGE OF THE URANIUM MINERALS IN THE COPPER KING MINE, LARIMER COUNTY, COLORADO*

George Phair and Paul K. Sims
U. S. Geological Survey, Denver Federal Center, Denver, Colo.

Ore deposition at the Copper King mine, Larimer County, Colorado, took place at three widely spaced periods and formed (1) an early high-temperature assemblage of magnetite, marmatite, pyrrhotite, pyrite, and chalcopyrite; (2) a later assemblage of black uranium minerals with siderite, silica, iron oxides, and sparse sulfides; and (3) supergene uranium minerals.

The high-temperature deposit is in metasediments enclosed by a younger granite. The richest sulfide ore, a heavy boxwork, selectively replaced amphibole skarn. Age determinations on ore magnetite by the helium method of Hurley and on monazite from associated pegmatites by the Th/Pb method indicate that both minerals formed in the late Precambrian.

The uranium was introduced into fractures in the earlier skarn ore and granite during or after a period of faulting and brecciation. It occurs in three black phases, which can be distinguished by X-ray diffraction: (1) Pitchblende, with the normal face-centered cubic diffraction pattern and high density, forms high-grade veinlets in the boxwork ore. It also occurs as disseminations and veinlets in the main breccia zone, where it is minutely intergrown with siderite and with (2) a new black uranium mineral giving a tetragonal diffraction pattern. This new mineral resembles the pitchblende in chemical composition but has a lower density. (3) Probable supergene UO_3-rich pitchblende amorphous to X-rays coats leached cavities in the boxwork sulfides. Good Pb/U ratio determinations on three samples of hard unaltered pitchblende from the main breccia zone indicate an early Tertiary age (62 $\pm$ 10 million years).

MOUNT SOPRIS STOCK, PITKIN COUNTY, COLORADO

H. D. Pilkington and C. L. Pillmore
Department of Geology, University of Colorado, Boulder, Colo.

The stock exposed on Mount Sopris is one of several Tertiary igneous bodies exposed along the crest of the Elk Mountains in central Colorado. The stock consists of granodiorite and was forcibly intruded into folded and faulted Permo-Pennsylvanian sediments. Extensive contact breccias, numerous inclusions, and notable variations in mineralogy suggest incorporation of considerable volumes of country rock by piecemeal stoping. Thermal metamorphism of the surrounding sediments resulted in formation of hornfels and was accompanied by considerable hydrothermal activity. Sericitization of the feldspars, intense albitization, and introduction of quartz to form graphic and myrmekitic intergrowths are deuteric-stage phenomena. Late hydrothermal activity produced several

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scattered minor deposits of lead-silver ore in the contact zone. It is suggested that the intrusives of the Elk Mountains are genetically related to the Princeton batholith and are cupolas projecting above a northwesterly extension of that body.

STRUCTURE AND STRATIGRAPHY OF THE GRAND HOGBACK SOUTH OF GLENWOOD SPRINGS, COLORADO

F. G. Poole
Dept. of Geology, University of Colorado, Boulder, Colo.

Laramide and later structures constitute the most conspicuous structural features of the Grand Hogback where it is exposed 10 to 20 miles south of Glenwood Springs, Colorado, in Garfield and Pitkin counties. Early Laramide deformation formed the northwest-trending Elk Mountain anticline, the steeply dipping west limb of which is the southernmost extension of the Grand Hogback. The fold that characterizes much of the Grand Hogback merges southward into the Elk Mountain thrust zone about 20 miles south of Glenwood Springs. Later movements in the White River uplift extended the Grand Hogback structure north of Rifle, Colorado, where the Eocene Wasatch and Green River beds are involved.

Sedimentary rocks range in age from Pennsylvanian (Minturn formation) to lower Eocene (Wasatch formation). The Maroon (4300–7000 feet), State Bridge (0–70 feet), Entrada (70–110 feet), Morrison (320–346 feet), Burrow Canyon (59 feet), Mesaverde (approx. 3600 feet), Ohio Creek ?, and Wasatch formations consist primarily of conglomerates, sandstones, siltstones, and shales and are mainly continental deposits, whereas the gypsiferous Minturn formation probably accumulated in a restricted basin. The Mancos group (approx. 5300 feet), which overlies the Dakota (?) (94–115 feet), is dominated by marine shale. A light-gray sandstone layer near the top of the Maroon formation thins southeastward and is thought to be a correlative of the Weber formation (Schoolhouse tongue).

Igneous rocks intruded the folded Permo-Pennsylvanian sediments during early Tertiary time. Miocene lavas rest unconformably on Mesozoic and early Cenozoic rocks.

CAMBRIAN OF SOUTHERN WYOMING

Alan B. Shaw
Geology Hall, Laramie, Wyo.

Seven Cambrian formations of west-central Wyoming extend eastward for varying distances toward central Wyoming, where major facies changes occur.

The Flathead sandstone is probably Lower Cambrian at its base in southwestern Wyoming, but elsewhere it is Middle Cambrian (no younger than *Bathyuriscus-Elrathina* zone). The Flathead in central Wyoming has been misidentified as the Upper Cambrian Deadwood formation.

The Death Canyon limestone is replaced east and south of the Wind River Range by a green, glauconitic shale sequence called the Gros Ventre formation in central, southwestern, and northern Wyoming. In south-central Wyoming unnamed brown sandstones and red beds are considered equivalent.

The Dunoir limestone is replaced in the eastern Wind River Basin by upper Gros Ventre limy shale. In the Bighorn Mountains, the lower part of the upper Gallatin limestone also grades into the Gros Ventre shale so that the Gros Ventre rises in time from west to east. The upper hundred feet of the group in the Wind River Mountains is upper Cambrian, but in the Bighorn Mountains the upper three-fourths of the formation is Upper Cambrian.

Post-Cambrian erosion removed most Trempealeauian rocks in west-central Wyoming and all Cambrian rocks in southeastern Wyoming, but in the Bighorn Mountains the upper Gallatin beds are basal Ordovician.

An angular unconformity separates the Flathead and the Madison limestone in southeastern Wyoming, but the age of the folding has not been determined definitely.

STRATIGRAPHIC RELATIONS OF THE TRIASSIC SHINARUMP CONGLOMERATE AND A PROMINENT SANDSTONE UNIT OF THE CHINLE FORMATION IN SOUTHEASTERN UTAH

J. H. Stewart and G. A. Williams
U. S. Geological Survey, Grand Junction, Colo.

Recent field work in southern Utah indicates that the Shinarump conglomerate is not so extensive as was formerly thought, and that rocks called Shinarump conglomerate in east-central and central Utah are actually a separate unit. Field relations indicate that the Shinarump conglomerate extends from the type section in northwestern Arizona to a northwest-trending line passing about 10 miles north of White Canyon, in southeastern Utah, where it pinches out. The Shinarump conglomerate is generally less than 100 feet thick and consists of light-colored coarse- to very coarse-grained cross-stratified conglomeratic sandstone.

A prominent sandstone in the Chinle formation lying 200 feet above the top of the Shinarump conglomerate in White Canyon correlates with the unit called Shinarump in central and east-central Utah. A new name for this unit will be proposed at a later date. The prominent sandstone averages about 50 feet in thickness and is composed of light-colored fine- to medium-grained cross-stratified conglomeratic sandstone. Northward from White Canyon this prominent sandstone overlaps the underlying part of the Chinle. The known distribution of this sandstone indicates that it was deposited as a mass about 60 miles wide and 150 miles long extending northwestward from southwestern Colorado to central Utah.

The Shinarump conglomerate and the prominent sandstone are both interpreted to be stream deposits formed by northwest-flowing streams.

INDEPENDENCE MOUNTAIN FAULT, NORTH PARK, JACKSON COUNTY, COLORADO

Richard F. Walters
School of Mineral Sciences, Stanford University, Stanford, Calif.

The Independence Mountain fault, which forms the northern physiographic and structural boundary of North Park, is unique because of its east-west trend and large southward displacement in this area of north-south structural alignments. The complex relationships indicate several phases of Laramide and post-Laramide history which can, in part, be dated by the relatively complete Tertiary section.

The fault trace extends eastward from North Park along the southern flanks of Independence and Watson mountains, terminating east of the Northgate Fluorspar mining district. The hanging wall, consisting of Precambrian granite gneiss, has overridden Mesozoic rocks overlain by the thick Paleocene Coalmont formation. Pre-thrusting deformation has formed an asymmetric northward-plunging syncline in the Coalmont formation. A late Tertiary boulder deposit partially conceals the fault trace on the crest of Independence Mountain.

The southward displacement is indicated by a fenster, 4 square miles in area, located less than a mile north of Independence Mountain. Triassic to Lower Cretaceous rocks, dipping southeast, are exposed in the fenster. The northeastern margin of the fenster is concealed by the tuffaceous Barstovian North Park formation, which fills a former stream valley. The fenster-fault trace relationships indicate minimum southward displacement of 4½ miles. The footwall rocks were strongly deformed prior to thrusting.

Late Tertiary normal faulting, trending northwest, occurs in the area. The eastern block is usually downthrown. These faults represent the last diastrophic phase or phases in the area. Locally, the late Tertiary faults have slightly modified the position of the Independence Mountain fault trace.

NONPEGMATITE BERYL OCCURRENCE, SHEEPROCK MOUNTAINS, UTAH

Norman C. Williams
Department of Geology, University of Utah, Salt Lake City, Utah

A white granite facies centrally located within a large red granite intrusive in the Sheeprock Mountains, Utah, contains an abnormal amount of nonpegmatite beryl. The beryl occurs as (1) small disseminated particles, (2) rosettes of myriads of crystals whose *c* axes radiate from a common center to produce spherical and nodular masses up to 2 feet in diameter, (3) in massive form in tiny seams and veinlets, and (4) distinct individual crystals in small aplite pods and in quartz veinlets.

Few typical pegmatites are present within the granite, and these contain little or no beryl. No pegmatites are found satellite to the intrusive. Other minerals found in nonpegmatite occurrences include fluorite, topaz, and samarskite.

Mapping and thin-section study leads to the following interpretation: (1) The granite intrusion was relatively rich in pegmatitic components. (2) The white granite facies represents a portion that solidified late and was enriched in the pegmatitic fluids which had been expelled from the solidified granite. (3) The pegmatitic residuum was not expelled or allowed to escape from the enriched white granite to form satellite pegmatite bodies as is normally the case late in the cooling history of a granite. (4) The pegmatitic residuum thus entrapped crystallized contemporaneously with and shortly after the host granite facies. (5) The beryl crystallized during this cooling period (a) as an accessory mineral in the granite, (b) as replacements of granite, (c) as fracture filling with partial replacement, and (d) as free crystals in aplitic segregates.

PETROGRAPHY IN THE DETERMINATION OF ENGINEERING PROPERTIES OF FOUNDATION ROCK

Vladimir E. Wolkodoff
Petrographic Lab., Engineering Labs., Bureau of Reclamation, Denver Federal Center, Denver, Colorado

In development of basic criteria used in design of large structures, the Bureau of Reclamation is carrying forward an extensive study of the stress-strain relationship of foundation rock. Petrographic analysis is a significant adjunct to the physical tests in selection and description of test specimens, explanation of results, and prediction of the properties of rock from new sites.

Results of the work are being issued progressively in a report entitled "Physical Properties of Some Typical Foundation Rocks." Thus far, data have been released on 38 varieties. Each rock type is described on an individual sheet; the following data are presented: petrographic description, unconfined compressive strength, triaxial strength in terms of the principal stress relations and Mohr's envelope, modulus of elasticity, Poisson's ratio, dynamic modulus of rigidity, specific gravity, and porosity.

In preparation for testing, specimens are prepared and grouped in the Petrographic Laboratory on the basis of texture, structure, and composition of the rock. Alteration, fracturation, and porosity are important criteria for subdivision.

For example, a suite of basalts from Oregon and of granites from Washington were subdivided on the basis of alteration. The principal stress relationships under triaxial conditions are as follows, where S_a is axial stress and S_l is lateral stress, in pounds per square inch: for basalt containing 3-5 per cent nontronite, $S_a = 24{,}570 + 7.4\ S_l$; for basalt containing less than 1 per cent nontronite, $S_a = 22{,}310 + 11.8\ S_l$; for granite, feldspars moderately altered, $S_a = 8{,}810 + 14.6\ S_l$; and granite, feldspars fresh, $S_a = 22{,}310 + 11.8\ S_l$. Other interesting relationships are presented.

ELK MOUNTAIN ANTICLINE, NORTH PARK, COLORADO

Harold F. York
University of Wyoming, Laramie, Wyo.

The Elk Mountain anticline is a sharply folded feature between the South McCallum dome on the west and the Precambrian mass of the Medicine Bow Mountains on the east. Sedimentary rocks in this area range in age from Permian to Paleocene with a total thickness in excess of 7000 feet.

The anticline trends northwest paralleling the axis of the Medicine Bow Range and plunges steeply beneath the alluvium of the Canadian River flood plain. The adjacent syncline to the east, flanking the Precambrian crystalline rocks, likewise plunges to the northwest.

A minor transverse fault caused by differential movement during folding extends northeast across the east limb of the fold; a reverse strike fault is believed to exist in the south part of the area, the resulting movement raising the Jurassic rocks into fault contact with those of the Lower Cretaceous. The youngest observed strata disrupted by this faulting are Lower Cretaceous. The asymmetric syncline to the west has surface exposures of Upper Cretaceous and Paleocene rocks which dip from 20° to 90°. No evidence of faulting in the Paleocene beds was observed. The time of faulting is assumed to be post-Paleocene with movement occurring along lines of weakness determined by the Laramide orogeny. On the basis of asymmetry, the folding and faulting appears to have resulted from compressive stresses acting from the northeast.

ABSTRACTS OF PAPERS SUBMITTED FOR MEETING IN BERKELEY, CALIFORNIA, DECEMBER 28–30, 1954 (SECTION E, AAAS)

STATUS OF PHOTO INTERPRETATION IN PETROLEUM GEOLOGY

Robert L. Anderson
Geophoto Services, Denver, Colo.

The tremendous increase in the use of photo interpretation as applied to petroleum geology has been one of the outstanding developments in geologic reconnaissance and exploration. Its acceptance as a rapid, confidential, low unit-area cost method of evaluation leading to the discovery of potential prospects has become almost universal by oil companies engaged in exploration. Experience has indicated that nearly all the actual or potential petroleum provinces of the United States are amenable to photogeologic evaluation. Foreign areas where accessibility is difficult present almost unlimited opportunity for future photogeologic exploration.

Reconnaissance and detailed photogeology is being done daily by about 100 geologists in the United States who have made the determination of structure and lithologic types of the earth's surface their special skill, and they have mapped approximately three quarters of a million square miles. Although some new petroleum discoveries now have been credited to photogeology the total is incomplete pending further evaluation of areas by geophysical means or by drilling.

Generally, in all types of photogeology the technique is identical. A geologist merely changes his viewpoint from the horizontal to the vertical. The tools of the trade are not complex; a simple folding stereoscope of the two-power lens-type is used in nearly all cases.

Photogeology has so quickly become an aid in petroleum geology for rapid, low unit-area cost reconnaissance that a full review of its status must await additional data for a complete analysis and evaluation.

COASTAL PLAIN MORPHOLOGY IN NORTHEASTERN HONDURAS

Brigham Arnold
Sacramento State College, Sacramento, Calif.

The reconnaissance of parts of the north coast of Honduras reveals several interesting problems in coastal-plain morphology. Special attention is paid to the form, extent, and materials of the coastal plain; the character of the coast line; present and past stream activities; indications of older, relatively higher stands of the sea; and vegetation cover. Some tentative conclusions are presented regarding relative shifts of sea level, the development of the coastal plain, and the course of events in shaping the present coast line.

PHOTO INTERPRETATION OF GEOLOGY AND SOILS IN CALIFORNIA

K. E. Bradshaw and R. E. Nelson
California Forest and Range Experiment Station, Berkeley, Calif.

The interpretation of geological formations and soils has been used in conjunction with vegetation-soil mapping in California since 1947. This mapping program involves a preliminary photo interpretation of timber stands and other vegetation elements to a minimum area of 10 acres, utilizing 1:20,000 scale photographs. This is followed by field mapping of vegetation species and soil series for each delineated area. In the process of mapping soil series, photo interpretation expedites the work and increases its accuracy. Geological formations are not mapped as such, but, because parent material is one primary factor in soil formation, identification of geology is essential.

The delineated photographs are studied in the field with a lens stereoscope. By means of reconnaissance inspections and detailed soil examinations, the mapper becomes familiar with local ground characteristics of the geology and soils and their corresponding photo characteristics. With this knowledge he can accurately locate certain soil boundaries, map the soils of some areas without actu-

ally traversing them, and detect or anticipate new soil conditions before they are observed on the ground.

The main factors used in geological interpretation are land forms, vegetation, and relief or drainage pattern. Soil series and depth classes of soils are detected by utilizing the same factors, plus detailed vegetation types or species, microrelief, and soil color or tone.

Examples of interpretations which can be made will be discussed and illustrated by slides made from aerial photographs, for example: (1) Granite compared with sedimentary formation, (2) Franciscan *vs.* Knoxville formations, (3) Monterey *vs.* Vaquero formations, (4) Alluvial and terrace *vs.* residual formations, (5) Jurassic basic igneous *vs.* Mississippian metasediments, (6) Land forms—miscellaneous land types, (7) Soil color—Sheetiron series, (8) Soil color—Obsidian series, (9) Soil microrelief—Yorkville and Laughlin series, (10) Soil microrelief—Tatu series, (11) Vegetation characteristics—Cummings and Huse series, (12) Drainage pattern—Maymen and Henneke series.

TOPONYMIC GENERICS IN THE UNITED STATES

Meredith F. Burrill
Division of Geography, U. S. Dept. of Interior, Washington, D. C.

This is a report of progress on a dictionary and atlas of generic terms in the names of physical features in the United States. Compilation of terms from the topographic quadrangles published by the Geological Survey and the Corps of Engineers has been completed. More than 700 terms have been collected. Most of them are applied with more than one connotation, and it is not uncommon for a term to be applied to six or more different types of feature. Many parts of the country, perhaps every part, have terms peculiar to it for features common to other areas, and regionally peculiar applications of terms used elsewhere. Some terms such as hope and folly that had a typographic connotation now largely lost are still used in the names of individual features. Experiment with a limited number of geologists and geographers suggests that the vocabulary of such persons includes somewhat less than one third of the list. No features were encountered that are invariably designated by the same typonymic generic, but the variability is much greater for some features, and in some regions than in others. Many of the terms occur in some connotations not covered by definitions in the dictionaries and glossaries that have been searched, and in some cases *only* in such connotations.

Distribution maps of a few terms have been completed and about 100 are partly done. In general they show a wider distribution of the terms than had come to the author's attention in the course of more than a decade of work with geographic names. The areas from which a term is missing on each map will have to be checked further to ascertain whether the absence of the term in a given area is an actual fact.

AERIAL COLOR PHOTOGRAPHY AS A TOOL FOR THE EARTH SCIENTIST

Robert N. Colwell
University of California, Berkeley, Calif.

For many years the geographer, geologist, forester, and soil scientist have recognized that aerial photographs can facilitate the making of various kinds of geographic inventory. At the same time these earth scientists are well aware of the limitations in conventional "black-and-white" photography. For example, even though there may be considerable differences in the actual colors of various soils, mineral deposits, vegetation types, or other features to be mapped, such differences may be virtually indistinguishable on conventional photographs because the reds, greens, yellows, and browns all tend to exhibit the same photographic tone, or shade of gray. This unsatisfactory condition has led to recent tests to determine the possible value of aerial color photography in various types of geographic inventory.

By means of lantern slides made from some of the best aerial color photography ever taken, an effort will be made to show situations in which such photography is far more helpful to the earth scientist than the conventional black-and-white photography. At the same time important limitations to the use of aerial color photography also will be stressed.

Following presentation of this paper, a display of aerial photographic transparencies will be made available to the audience by means of which it will be possible to compare photographic images taken on (1) panchromatic film, (2) infrared film, (3) aerial ektachrome film, and (4) camouflage detection film (a special type of color film originally designed for military use).

PHOTOGEOLOGY IN ARCTIC AREAS

William E. Davies
U. S. Geological Survey, Washington, D. C.

The increase of construction activity in the Arctic has been accompanied by the extensive use of photogeology in the planning stage. Site selection, evaluation of construction materials, and sources of water supply often are based on interpretation of aerial photos. In addition photogeology has been an important factor in recent exploration and in maneuvers and testing operations of the armed services.

The areas involved in the photogeology work have been large, often covering 25,000 or more square miles with data interpreted in detail commensurate with 1:250,000 scale maps. Smaller areas are covered at scales as large as 1:20,000. The interpretations are generally of areal geology and are devoid of any specific subject-type of interpretation. In addition to the usual techniques of interpretation using landforms, photo tones, and textures, the patterns ascribed to frost features are of great significance in interpreting unconsolidated deposits. These patterns are greatly enhanced in photos that were taken when a light snow cover was on the ground.

Recent use of helicopters as auxiliary means of obtaining aerial photos presents great possibilities in improving photogeology. By using the helicopter at altitudes from 50 to 2000 feet above the ground and photographing with ordinary 35 mm. kodachrome, many features not decipherable on ordinary black and white photos can be determined. Kodachromes made from helicopters when used in conjunction with regular black and white vertical aerial photography increase the speed and accuracy of interpretation to the point that the costs of the helicopter are more than compensated for.

COMPARISON OF THE FREEZES WHICH HAVE AFFECTED THE SOUTHERN CALIFORNIA CITRUS INDUSTRY

Robert W. Durrenberger
Los Angeles State College, Los Angeles, Calif.

Commercial plantings of citrus in California date from the 1840's, but large-scale development of the industry awaited the building of the transcontinental railroads. These early plantings were made indiscriminately throughout the State. The present areas of citrus production have evolved as a result of this system of trial-and-error planting.

One of the most important factors delimiting the citrus-growing areas is temperature. Where low temperatures of long duration occur frequently, citrus cannot be grown at a profit, and the trees may be damaged or killed. The amount of damage during a particular period of low temperatures is dependent upon a number of factors, including the degree of coldness, and the duration of low temperatures.

"Frosts" occur almost every year. Prolonged periods of unusually low temperatures, called "freezes", occur at longer intervals. Temperature records for the years 1853–1854, 1878–1879, 1879–1880, 1882–1883, 1886–1887, 1912–1913, 1921–1922, 1936–1937, and 1948–1949 show temperature conditions typical of freeze years. Of these, 1853–1854, 1886–1887, 1912–1913, and 1936–1937 were the most severe.

RECONNAISSANCE METHODS OF MEASURING EROSION

Clark H. Gleason
California Forest and Range Experiment Station, Berkeley, Calif.

People who manage land want to know the speed of erosion, in order to assess its importance. Whether or not erosion is or has been active on slopes and in channels can be determined qualitatively by observation. But the quantitative measurement of erosion in different parts of a watershed is more

difficult because catch basins are seldom located at the desired points, and they do not separate the erosion products of slopes and channels. What we need are semiquantitative methods of measuring erosion where it takes place. These methods should not require costly installations, and they should be easy to use by one or two persons without disturbing the land. Such methods would have practical application, for example, in determining the amount of erosion associated with different land-use practices.

The paper discusses some methods used to measure erosion in California, such as datum-level stakes and local counts of gullies, and suggests the need for more simple but dependable techniques. It then describes several methods that have been devised for making such measurements and reports the results obtained with them. Included are such methods as installing permanent transects for repeated measurement of sheet and gully erosion, establishing spikes with washers to record deposition following erosion, and placing bottlecaps so as to form pedestals that indicate erosion. Wider testing of these methods is suggested, together with checking their indications against the quantity of eroded material caught in suitable boxes or basins.

FOSSIL SOILS AS A KEY TO THE PAST CLIMATES OF THE BONNEVILLE BASIN

Vasyl Gvosdetsky and H. Bowman Hawkes
University of Utah, Salt Lake City, Utah

Three main groups of soils are distinguished in the area of ancient Lake Bonneville: (1) post-Pleistocene, (2) Pleistocene, and (3) pre-Pleistocene. The post-Pleistocene fossil soils are generally found within the recent alluvial flood-plain deposits; these soils are coincident with the post-Pleistocene Climatic Optimum and may be identified as altithermal soils. Pleistocene fossil soils are represented largely by the Wisconsin interstadial (Brady) soil. This soil is generally found between the lower and upper deposits of Stansbury Lake. The areal distribution of Pleistocene soils is somewhat similar to the pattern of recent living soils. Differences between them are more in the nature of intensity than in a basic change of pattern. Fossil soil profiles have been observed in a belt adjacent to the Wasatch Mountains; this area corresponds closely with the present pattern of brown steppe and chestnut soils. West of the present steppe zone is a true desert with poorly developed soil cover; within the desert zone fossil soil profiles have yet to be identified. The Brady fossil soil is observed farther west, however, than the belt of the present-day living steppe soils. The general appearance of this Wisconsin interstadial fossil soil suggests that it was developed under more humid and cooler conditions than the present climate of the same locality. On the other hand the interpluvial (pre-Wisconsin) times of Pleistocene were probably drier than the present climate. Pre-Pleistocene soils are radically different from the Pleistocene and post-Pleistocene soils; they are typically deep red-brown soils that developed under moist subtropical conditions.

SOME FEATURES OF THE DISTRIBUTION OF CONIFERS IN EASTERN ASIA

Walter Hacker
San Francisco State College, San Francisco, Calif.

The coniferous genera in the native vegetation give character to the appearance of the geographic regions of Eastern Asia. The number of coniferous families and genera is so limited and their distinctive features are so conspicuous and easily discernible that even a geographer who is not trained in botany can recognize them in the field and utilize them in his areal description. Such general terms as needleleaf-deciduous, needleleaf-evergreen, and mixed forest, while perhaps of value in a world-wide classification, tend to be obscuring rather than enlightening when applied to smaller areas.

Eastern Asia is the meeting ground of a number of coniferous genera of wide distribution and the home of several endemic genera and species. All but one of the coniferous families are represented in the area. Of the more than 50 existing coniferous genera in the world about half are found in Eastern Asia. The distribution and association pattern of these is discussed on the basis of conventional geographic areas and the floristic regions of Ronald Good.

Areas of coexistence of conifers with genera of three other conspicuous families—the Cycadaceae, Palmaceae, and Pandanaceae—are pointed out. In the southernmost zone of Eastern Asia the

presence of genera of the Podocarpaceae enhances the tropical or exotic appearance of the forests. In the landscape or in creations of art the presence of both conifers and bamboo in commonly held typical for Eastern Asia.

ISOTOPE-RATIO VARIATIONS IN STRONTIUM AND THE PRESENT STATUS OF THE ^{87}SR METHODS OF GEOLOGIC AGE DETERMINATION

L. F. Herzog
Department of Geology and Geophysics, Massachusetts Institute of Technology, Cambridge, Mass.

The spontaneous beta decay of rubidium-87, with a half life of about 60×10^9 years, produces strontium-87. Two "strontium age methods" are under investigation, depending on measurement of (1) the Rb/Sr ratio and radiogenic ^{87}Sr in Rb-rich, Sr-poor samples, and (2) the expected variation in ^{87}Sr relative abundance in sets of samples of particular Sr-rich, Rb-poor minerals forming time-of-separation series with respect to particular well-mixed parent reservoirs containing both Rb and Sr (such as oceans). The results of the accelerated research of the last decade on these methods, made possible by improvements in mass spectrometry, ion-exchange chemistry, and the availability of stable isotope tracers, will be discussed, with particular emphasis on current work at M.I. T. Results include: several dozen "ages" from lepidolites by method (1), some of them extreme; demonstration of fractionation of the Sr isotopes both by natural processes and by certain analytic techniques; indications that the ^{87}Sr relative abundance variation in "common" Sr effect is only perhaps 20 per cent of that anticipated, and, hence, that the currently listed geochemical Rb/Sr ratio of about 1 is too high by about a factor of 5; and determination of Sr and Rb in certain geologic samples by isotope dilution. Results of recent analyses of meteorites will be given, and their bearing on the problems of the age and composition of solar system and earth discussed.

AGGRADATION AND IRRIGATION IN THE MIDDLE RIO GRANDE VALLEY: THE BERNALILLO SECTOR

Wilfred D. Kelley
University of New Mexico, Albuquerque, N. M.

Irrigation agriculture in the Middle Rio Grande Valley of central New Mexico during the last 75 years has been affected by rapid aggradation of the river bed and deposition by arroyos on the flood plain. Several studies have been made of changes in the river regime arising from increased use of water upstream, construction of diversion dams, and runoff and entrenching of tributary drainage, but only general estimates have been made of the effect on irrigation agriculture.

An analysis is made of the effects of aggradation and arroyo deposition on the agricultural lands in the Bernalillo sector north of Albuquerque. These lands lie below the mouth of Jemez Creek but upstream from the Puerco and Salado, the major silt producers of the Middle Rio Grande, and in this sense are representative of neither the worst nor the best agricultural conditions of the Middle Valley. Cultural remains indicate agricultural settlement in the area for at least 500 years and provide evidence of increasing damage to irrigated lands due to aggradation.

REVIEW AND PROSPECTUS OF PHOTOGEOLOGY AND PHOTOGEOGRAPHY

Arthur C. Lundahl

Recent progress in the application of photography to the solution of a wide range of problems in geology and geography is briefly summarized. Basic principles, definitions, and developments are reviewed as the subject material is resolved into considerations of (1) indirect uses of aerial and ground photography for mapping purposes, and (2) direct uses of photography or photographic mosaics as a basis for many types of annotations or transparent overlays. These bear geological, geographical, geochemical, geophysical, geobotanical, and other earth-science field data which collectively may offer "convergence of evidence" conclusions to the investigation at hand. The investigations may range from determinations of location and type of mineral existence to the selection of a site and reorientation of a new national capital.

The paper proceeds with general considerations of future prospects in photogeology and photogeography in terms of the development of new techniques, new equipment, suggested test areas, training and the human resources required. More detailed attention is directed by means of illustrations to a growing variety of stereoplotting equipment developed for (1) preparing photogrammetric base maps, (2) transferring geological or geographical data interpreted and delineated on aerial photographs to base maps, and (3) measuring or otherwise assisting in the interpretation of earth surface features.

The author concludes:

(1) That the contribution of photography to scientific research has been so extensive and offers such great potential that a realistic evaluation is difficult to make.

(2) That aerial photography alone represents the most significant tool yet provided which can be used so widely, quickly, and relatively inexpensively for earth-science investigations.

(3) That generally adequate photogrammetric instruments are presently available, but new, more highly specialized equipment should be so designed that a high technical knowledge of photogrammetry will not be required of the user.

(4) That the full impact of the importance of photogeology and photogeography has not yet been recorded, and we are just becoming generally aware of the possibilities they offer in combinations with other instrumentational records and earth-science data in the economic, scientific, and cultural development of man.

(5) That despite the foregoing conclusions we should be wary of "overselling" photogeology and photogeography and clearly recognize that high-level photo-interpretation ability depends upon the skill of the interpreter in recognizing under the stereoscope the objects with which he is familiar on the ground. This in turn is dependent upon his having a solid professional background in geology or geography. Finally, it is of paramount importance that photo interpreters, whether they be geologists or geographers, spend sufficient time in the field with photos and stereoscope to develop their abilities to correlate ground features with their photographic appearance.

SILICOFLAGELLATA, A NEW TOOL FOR THE GEOLOGIST

York T. Mandra
San Francisco State College, San Francisco, Calif.

When compared to the record of Foraminifera, ostracods, pollen, or other fields of geology during the last 50 years, very little progress has been made in the field of Silicoflagellata research. In this interval only nine men (V. Zanon, T. Yanagisawa, P. Schulz, Y. Mandra, K. Gemeinhardt, R. Hovasse, G. Hanna, J. Frenquelli, and G. Deflandre) have made major contribution to the study of these micro-organisms. In spite of this fact and the fact that only two of these men have published on the detailed stratigraphic aspects of Silicoflagellata, it is now becoming apparent that these organisms might have use as stratigraphic tools.

Species of this group which are restricted in vertical range and yet have a very widespread horizontal range have been reported. The minimum limit of the vertical range is less than 10 feet, and the maximum of the horizontal range is occurrence of species in six of the seven continents. In addition, groups of species associated as Oppelian zones—zones of unique overlap—will soon be reported. One more advantage is the fact that the morphology of the Silicoflagellata is so simple and unique that even a person not trained in the identification of these organisms will have no trouble differentiating species.

LANDSCAPE AND CLIMATE: THE INFLUENCE OF OPEN PINE FOREST ON DAYTIME TEMPERATURE OF THE SIERRA NEVADA

David H. Miller
Quartermaster Research Laboratory, Natick, Mass.

A salient feature of the local climates that develop in the Sierra Nevada of California between winter and spring snowstorms is the marked daytime warmth, manifest in an air temperature of 50° or higher and in high rates of snow melt. This warmth is anomalous in the presence of a snow cover, which by Boeikov's classic theory produces very low temperatures.

The high daytime energy level in the local environment results from absorption of strong insolation by the dark elements of the natural landscape—the lodgepole pine stands, which cover about 40 per cent of the surface. Stands are open, and the edge effect is dominant, so that more than half of the intense short-wave radiation is absorbed.

Foliage is heated as much as 20°F. above air temperature, and from it large amounts of latent and sensible heat are transferred to the local air; in a midday hour in spring, these transfers are, respectively, 15 and 25 calories per square centimeter of stand. Passage of this heat into air trapped between concave topography below and a subsidence inversion aloft results in the observed anomaly of daytime temperature, in spite of the thermal sink represented by the snow. In conjunction with anticyclonic upper-air circulation and the characteristics of the snow surface, the forest stands thus determine an important characteristic of the local climate.

GEOGRAPHY OF THE GENUS *PINUS*

Nicholas T. Mirov
California Forest Experiment Station, Forest Service, U. S. Dept. of Agriculture

The genus *Pinus*, comprising about 80 species, belongs to the family Pinaceae of Gymnosperms. The genus is subdivided into two subgenera: the larger, Diploxylon (hard pines) and the smaller, Haploxylon (soft pines). Pines appeared on earth probably at the end of the Paleozoic era. Paleobotanic records, however scarce, show that during Jurassic times pines were found all over the Northern Hemisphere. No fossil pines have been detected in the Southern Hemisphere.

A study of the present distribution of pines reveals many interesting geographic features. All pine species but one are found in the Northern Hemisphere. *Pinus merkusii* just crosses the equator on Sumatra. In the New World, pines do not go farther south than Nicaragua.

Different species of pines grow from sea level up to 12,000 feet altitude, from the arctic regions to the tropics. They grow in semideserts and in swamps, in acid soils and on limestone cliffs. Occasionally pines hybridize in nature.

About half of all pine species occur in California and Mexico. There are only 7 per cent in Europe; about 30 per cent in California; 30 per cent in Mexico; only 4 per cent in Northern Asia, but about 20 per cent in Southeastern Asia. There are no pines in Africa, except Aleppo pine near the Mediterranean coast and one species on the Canary Islands. Most diversity occurs in tropical highlands of Mexico and to a lesser degree in Southeastern China. This diversity is caused by geographic and climatic conditions that are inducive to the appearance of mutants and favorable for hybridization. The tropical highlands, where there is a great diversity of pines, may be considered as secondary centers of development.

It is impossible at present to indicate the primary geographic center of the origin of pines.

FURTHER NOTES ON METALLIC SPHEROIDS AT THE ARIZONA METEORITE CRATER

H. H. Nininger

In previous papers the author has described several varieties of small meteoritic particles believed to have resulted from the vaporization of the principal mass of the crater-forming meteorite in Arizona. The most important variety of these particles, the "metallic spheroids", is here discussed quantitatively on the basis of measurements in 59 locations within a radius of 2 miles of the crater, and reconnaissance collecting in more than 100 other locations extending to distances up to 6 miles from the crater rim. An estimate of the total tonnage of these particles in the upper 4 inches of soil is submitted.

The question as to whether these particles may have had their origin in the form of strippings from the surface of the meteorite during flight and upon penetration of the rock strata or as a liquid spray from the crater pit instead of being condensed from a metallic vapor cloud is considered in the light of the quantity present, the age of the crater, their distribution, and their composition. The composition of spheroids, the meteorite fragments, and of a new variety of particle here described for the first time are compared. The distribution and probable origin of these new particles are discussed.

For the first time metallic spheroids and other condensation products are reported from depths down to 4½ feet below the surface in the ejectamental blanket on the crater rim. Material taken from this depth where it has had protection from sudden temperature changes, attrition, etc., exhibits several new and interesting features.

AGES OF DWELLINGS IN THE UNITED STATES

Edward T. Price
Los Angeles State College, Los Angeles, Calif.

Geographers may find several reasons for examining the ages of dwellings. As semipermanent features of the landscape, dwellings continue to reflect the tastes and needs of their original builders. The distribution of dwelling ages in a given area depends on and may be an indicator of such historical and cultural conditions as recency of settlement, growth of population, durability of structures, vitality of the economy, and past disasters.

The data presented are taken from the Census of 1940, which contained more detailed information on dwelling ages than any other. Maps show the median dwelling ages by States, with the highest medians in northern New England and relatively low medians in the South and West. The medians are better understood when plotted on a graph against the date when the corresponding area attained half its 1940 population. Median dwelling ages depend largely on the time of settlement and rate of population growth, but houses in the South are younger than those in other parts of the United States with the same history of population growth. A similar graph for the largest cities shows no systematic regional variation.

SAHARA IS NOT ALL DESERT

W. A. Rockie
Soil Conservation Service, Portland, Ore.

In 30,000 miles of travel for the 1953–1954 International Sahara-Sudan Scientific Expedition, extending from the Mediterranean Sea on the north to the Gulf of Guinea on the South and between longitudes 3°W. and 9°E., observations were made on several specific factors which may play an important part in determining the land use of the past, present, and future. They usually included all of the following: altitude, the lay of the land, the degree of slope, the soil, the probable climate, the native vegetation, the evidence of wind and water erosion, and the type of agriculture, including any efforts toward soil conservation.

The Sahara presents fully as varied a topography as the intermountain country of America west of the Rockies. Geologically the area probably is the most easily read portion of the earth's land surface. The soils are predominantly sandy; silts and clays are the exception. Climatically it presents a wide range of conditions, both as to temperature and precipitation. It is in this latter area of study that vast areas which are not true desert must be explained. Previous publications about this area contain some extremely irresponsible and untrue statements about the climatic and soil conditions which prevail here.

PHOTOGEOGRAPHY, PHOTOGEOLOGY, AND THE AIRPHOTO INTERPRETATION KEY

John H. Roscoe, Chief,
Photo Reconnaissance Utilization Section, U.S. Air Force

Photogeography and photogeology are concerned with the procedure of solving geographical and geological problems by the analysis of aerial-photo images. Recent developments in optics, emulsions, and film processing have improved resolution and increased the value of aerial photography as a tool of science, but even with the finest resolution photo interpreters can neither adequately determine nor properly describe phenomena with which they are unacquainted. Individual photo analysts cannot be thoroughly trained in all the earth sciences nor can they be fully familiar with the myriad photo images cast by the earth's surface and the cultural patterns superimposed upon it. Therefore, a device is required to provide the earth-science photo analyst with the information necessary to effect

rapid and accurate solution of the problem concerned. The most practical system devised thus far to solve this requirement is the photo-image reference file, containing annotated photo images of the natural and cultural objects most necessary for an earth scientist to know. These annotated photo images, organized by subject or region, are called *airphoto interpretation keys*.

Airphoto analysis is not intended to replace field investigation except for areas inaccessible to earth scientists. Photo interpretation keys permit the photogeographer or photogeologist to construct an *airphoto landscape*. Confirmation of the interpretation as well as supplementary analyses are then made by photo-planned field traverse. The result is a study of the *true landscape*, including certain patterns and relationships which are not apparent from the ground, made more rapidly, more accurately and with less expense than would be possible by surface research alone. Many earth-science problems may now be solved by photogeographical or photogeological techniques. Some of these problems cannot be solved otherwise. The airphoto analysis technique has become requisite for the earth scientist.

WINDS, CURRENTS AND EARLY HUMAN MIGRATIONS BY SEA

Erhard Rostlund
University of California, Berkeley, Calif.

Similar culture traits on opposite shores of certain water bodies suggest cultural dispersal by means of voyages, and in some instances it must be assumed that waters were crossed by man at a very early time. The question raised is what type of craft and degree of navigational skill must have been required for certain voyages. As an example, the situation at the Strait of Gibraltar is discussed. It is suggested that the determination of the physical possibility of very early voyages, especially insofar as winds, currents, and routes are concerned, is a task to which geographers can contribute.

POLITICAL GEOGRAPHY OF PORTUGAL

Dan Stanislawski
University of Texas, Austin, Texas

The Iberian peninsula is sufficiently homogeneous physically and culturally so that its division into more than one political unit may be unreasonable and unfortunate. This, certainly, is the view of most Spaniards. If there were only one political power in the peninsula, the Spaniards, who occupy more than four-fifths of the land surface and make up about four-fifths of the population, would be overwhelmingly dominant.

The Portuguese, who would be submerged more than merged in such a case, maintain that not only is there an evident distinction to be made between Spain and Portugal, Spaniard and Portuguese, but that it is based on demonstrable fact. Some defend their case in terms of physical conditions, others in the light of historical and human decisions. The writer believes the Portuguese are justified in this contention, and although each of their arguments has some merit the first seems to have greater weight.

Fundamental physical facts often have been decisive in the events of history in the peninsula, and even when the decision seems to be "human" and perhaps personal it still is based on cultural attitudes originally rooted in physical conditions.

Through history and, indeed, into pre-history insofar as we can interpret it, the "culture regions" of the peninsula have had a distribution and extent roughly comparable to the present. Each of these is more or less coincident with a physical region.

Portugal, with Galicia, is an "Atlantic" physical region and has always shown a unique cultural character.

TECOLOTE TUNNEL GEOLOGY

Robert E. Trefzger
U. S. Bureau of Reclamation, Goleta, Calif.

Tecolote Tunnel, 6½ miles long, is being drilled through the Santa Ynez Mountains to bring water from Cachuma Reservoir to the coastal area near Santa Barbara, California. Rocks penetrated are

all of sedimentary origin, mostly marine, and range from the Upper Cretaceous Jalama formation to the Upper Miocene Monterey formation. Most of the tunnel is within a large east-west trending anticline cut and displaced considerably near its surface trace by the Santa Ynez fault. Other faults with significant displacements together with many minor faults complicate the structural picture.

Difficulties and delays in driving the tunnel have resulted from a variety of geologic conditions and include two explosions of accumulated methane seeps; quantitites of hydrogen sulphide from two highly charged water flows; runs of water-washed loose sand and water-washed finely brecciated siltstone; and large water flows from open fractures and joints, mostly in the lower Cozy Dell and Matilija formation. The maximum total flow at the south portal has been 9100 gpm. Gradual increase of water temperatures as the south heading penetrated deeper into the central portion of the range reduced working efficiencies and rate of progress. Maximum temperature observed was 117°. On October 1, 1954 about 3325 feet of tunnel remained to be dug, all in the Jalama formation.

SIGNIFICANCE OF INTEGRATED RIVER-BASIN DEVELOPMENT

S. J. Ware
U. S. Public Health Service, Logan, Utah

Careful and forward-looking development of our natural resources is more important now than ever before in the history of the United States. For a nation whose growth has been based on increasingly rapid exploitation of these resources, this fact has become apparent with alarming clarity in recent years. Planning and execution of fundamental programs to conserve our land, water, and mineral treasures is a "must" if we are to continue leadership in world affairs.

The Tennessee Valley Authority has not necessarily established the pattern for river-basin development over the country. To the contrary, many a staunch supporter of the Inter-Agency Committee approach being worked out in the Arkansas-White-Red Basins and elsewhere would strongly oppose anything that smacked of an "Authority" type of organization. Many of the centralized functions which have proved successful in TVA would prove the downfall of a developmental agency in the Missouri River Basin and probably in all the basin areas of the West.

Co-ordinated inter-agency planning as a preliminary to overall natural resources development throughout the United States is comparatively young. The utilization of these resources has been proceeding at an accelerated pace since the early exploration and settlement of the continent by white men. For most of that time private exploitation, often completely unregulated, has been without plan or cognizance of the future, but rather for the greatest short-term gain. Since the days of Theodore Roosevelt and Gifford Pinchot there has been an increasing recognition of the need for participation by public agencies, State and Federal, for careful and conservation-minded natural-resources development. Especially since the year of extended drought during the 1930's more attention has been given to co-operative and organized private, State, and Federal planning and regulated development of these resources.

Integrated river-basin development programs for multiple-purpose use have been effectively under way since the early 1940's. The co-ordinated plan of the Bureau of Reclamation and the Corps of Engineers for the conservation, control, and use of water resources in the Missouri River Basin presented a co-ordinated multipurpose plan for the development of an area amounting to one-sixth that of the entire United States. To provide a common meeting ground for representation of all interests in gearing the accomplishment of this and similar plans for the necessary future addenda to the past interests of the nation, the Missouri and other river basin inter-agency committees, consisting of private and State representation as well as Federal, have been formed. The counterpart of these committees in Washington is the Federal Inter-Agency River Basin Committee, reconstructed at Departmental level. Plans and action programs formulated by these committees represent co-ordination of the existing and future programs of many agencies whose experience with the problems encountered extends back for many years. This organizational structure represents no broad new governmental authority created for purposes of development, but rather consists of a unique and effective program of enlightened co-operation in drafting and carrying out a synchronized plan in which the various agencies concerned work together to solve their common problems on a reasonable basis.

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日本近海深浅図

BATHYMETRIC CHART OF THE NORTHWEST PACIFIC

1/8,000,000 (Lat. 35°)

昭和19年マデノ諸資料ニヨリ編修スル

CONTOUR INTERVAL = 500m.

DEPTH AND ELEVATION POINTS IN METRES

LEGEND

Smt = Seamount
A. = Atoll
Is = Islands
I. = Island
Rf = Reef

12 0° 13 0° 14 0° 15 0°

60°

50°

SIBERIA

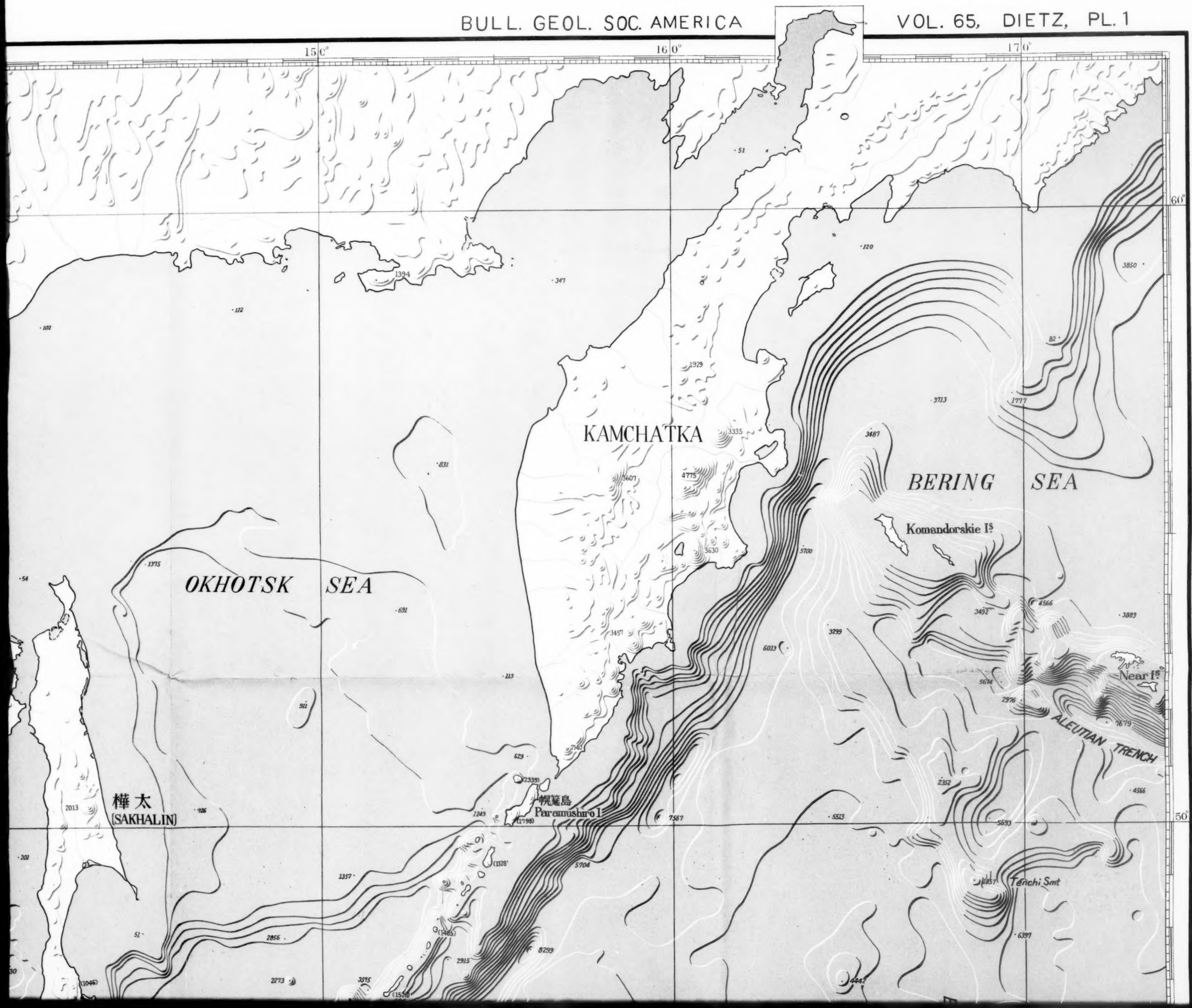
OKHOTSK SEA

Amur R.

樺太
(SAKHALIN)

満州
(MANCHURIA)

Paran


150°
160°
170°
60°
50°
KAMCHATKA
BERING SEA
OKHOTSK SEA
Komandorskie Is
Near Is
ALEUTIAN TRENCH
Tenchi Smt
樺太
(SAKHALIN)
幌筵島
Paramushiro I
1394
347
122
102
51
120
3850
82
1929
3713
1777
3335
3487
3607
4775
831
3630
5700
1375
54
691
3457
3492
4566
3889
3299
6033
113
911
5674
2976
1679
629
2340
2352
4566
2013
926
1249
(1798)
7587
5533
5593
201
(1328)
5704
1357
(1485)
2856
8299
2915
51
1457
Tenchi Smt
6397
2273
3595
(1526)
(1046)
4447

Amur R.
樺太
(SAKHALIN)
満　州
(MANCHURIA)
Vladivostok
日本海
JAPAN SEA
HOKKAIDO
択捉島
(1639)
Etorofu I.
朝鮮
(KOREA)
Seoul
黄海
YELLOW SEA
HONSHU
日本
NIPPON
支那
CHINA
SHIKOKU
KYUSHU
Hachijo I.
八丈島
Myojin Rf
Tokyo
Shanghai
東海
EAST CHINA SEA
Ramapo Deep
10680
50°
40°
30°

樺太
(SAKHALIN)

帽窪島
Paramushiro I.

ALEUTIAN TRENCH

Tenchi Smt

Jimmu Smt

Suiko Smt

Nintoku Smt

Jingu Smt

Qjin Smt

Kinmei Smt

Yuryaku Smt

Kanmu Smt

EMPEROR SEAMOUNTS

択捉島
(1639)
Etorofu I.

HOKKAIDO

日本海溝
JAPAN TRENCH

日本
NIPPON

Ramapo Deep
10680

北太平洋
NORTH PACIFIC OCEAN

56°
40°
30°

YELLOW SEA

支那
CHINA

Shanghai

東海
EAST CHINA SEA

KYUSHU

SHIKOKU

Hachijo I.
八丈島

Myojin R.

Ramapo Deep
10680

小笠原群島
Bonin Is.

沖縄島
Okinawa I.

Daito Is.
大東島

琉球海溝
Ryukyu Trench

沖大東島
S. Daito I.

KYUSHU-PALAU RIDGE

Iwo I.

台湾
[FORMOSA]

Parece Vela Rf
沖ノ鳥島

Uracas I.

PHILIPPINE SEA

MARIANA Is.

Pagan I.

LUZON

Saipan I.

Guam I.

MARIANA TRENCH

PHILIPPINE TRENCH

Cape Johnson Deep
10497

Emden Deep
10400

10863
Challenger Deep

Ulithi A.

Yap I.

Fais A.

Yap Deep
8120

Yap Trench

Palau Is.

Palau Deep
8138

Palau Trench

WEST CAROLINE Is.

Eauripak A.

SULU SEA

MINDANAO

30°

20°

10°

北　太　平　洋

NORTH PACIFIC OCEAN

Kinmei Smt

Kanmu Smt

Yuryaku Smt

Ramapo Deep
10680

Bonin Is

Iwo I.

南鳥島
Marcus I.

Wake I.

Uracas I.

MARIANA Is

Pagan I.

Saipan I.

Guam I.

MARIANA TRENCH

MAGELLAN SEAMOUNTS

10863
Challenger Deep

MARIANA

EAST CAROLINE Is

Taongi Atoll

Bikini A.

Enewetok A.

Kwajalein A.

MARSHALL Is.

Wotje Atoll

Jaluit Atoll

Kusaie I.

Ponape I.

Truk Is

Nomoi Is
(Mortlock)

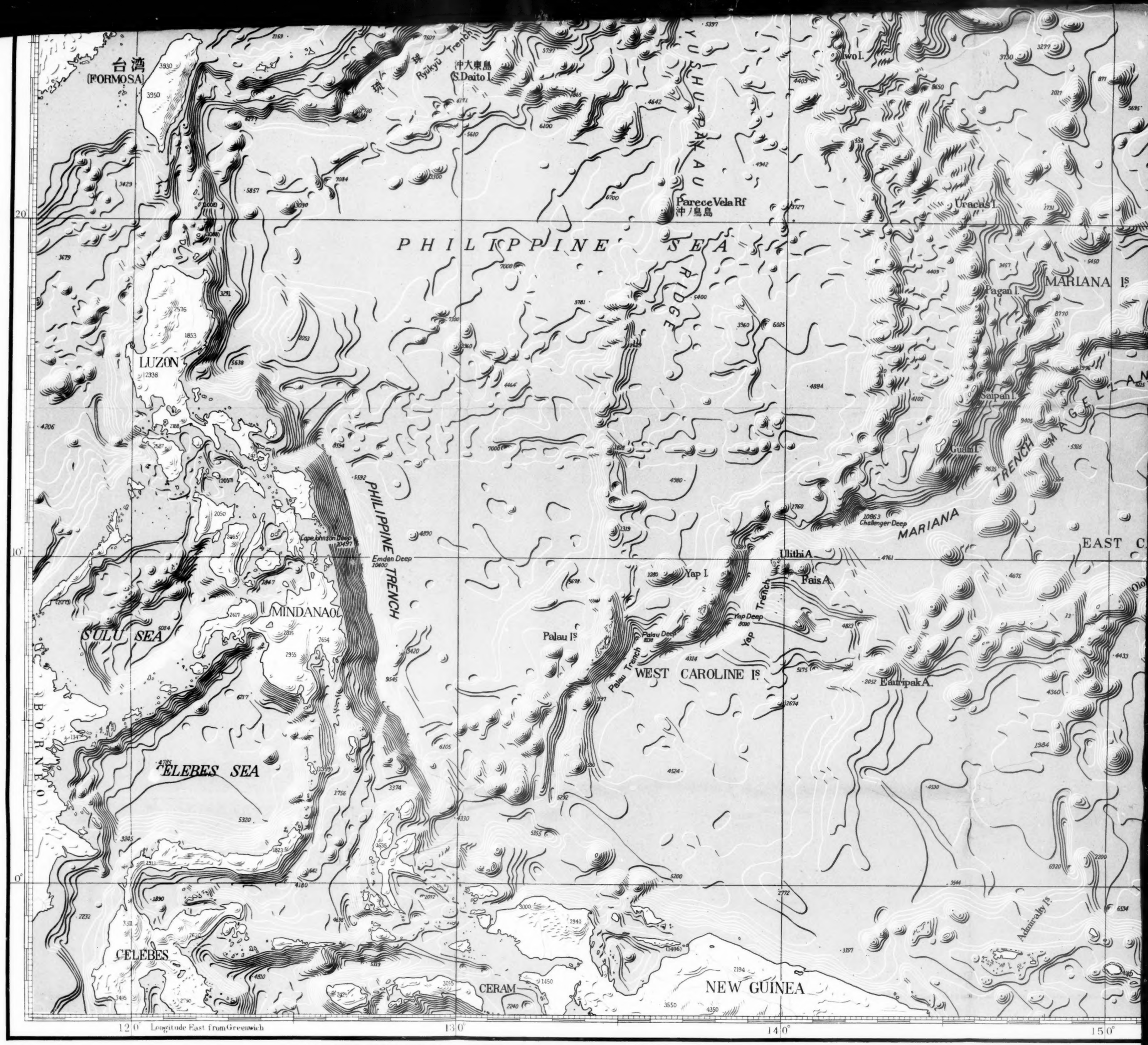
Ulol A.

Eauripik A.

30°

20°

10°



MARINE GEOLOGY OF NORTHWESTERN PACIFIC: DESCRIPTION OF JAPANESE BATHYMETRIC CHART 6

Iwo I.

南島島
Marcus I.

Uracas I.

MARIANA Is

Pagan I.

Saipan I.

Guam I.

MARIANA TRENCH

MAGELLAN SEAMOUNTS

10863 Challenger Deep

EAST CAROLINE Is

Olol A.

Truk Is

Ponape I.

Eauripak A.

Nomoi Is (Mortlock)

Kapingamarangi A.

Admiralty Is

Wake I.

Taongi Atoll

Enwetok A.

Bikini A.

Kwajalein A.

Wotje Atoll

MARSHALL Is

Jaluit Atoll

Kusaie I.

GILBERT Is

Nauru I.

Ocean I.

20°

10°

0°

150°

160°

170°

JAPANESE BATHYMETRIC CHART 6901.

COMPILED AND PRINTED IN THE JAPANESE HYDROGRAPHIC OFFICE, 30th MAY 1953.

Nº 6901

(94·97×65·05)